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**RISK MITIGATION FOR THE MINING
INDUSTRY THROUGH SUSTAINABLE
WATER SOLUTIONS**
- Case SERENE

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ABSTRACT

Sonja Kuokkanen: Risk mitigation for the mining industry through sustainable water solutions? – Case SERENE

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This thesis examines water risk management in the mining industry in water scarce regions. The aim is to increase understanding of water risk management in the industry by bringing the previous research and expert interviews together. In addition, the study involves examination of the SERENE project which is a real-life project aiming to bring a new water balance system to the market. The aim is to answer two research questions, firstly “What kind of water related environmental risks does the mining industry have in water scarce areas” and secondly “How can new sustainable water solutions mitigate water risks in the mining industry”.

The literature review has been carried out by examining the mining industry in water scarce regions and the risk management practices in the industry by having the environmental perspective as a core of the study. There's a lot of previous research on sustainability practises in the mining industry. It has been a controversial subject, because it is an industry that interacts with limited natural resources. However, nowadays many mining companies include the environmental and social aspects as part of their strategies. Water management in the mining industry has attracted public attention due to recent realized dam accidents which have had catastrophic consequences. The previous research on water risk management discusses that it is becoming an essential part of the sustainability field especially in water scarce regions, where the availability of freshwater is poor. However, there are certain challenges for the research on water risk management in the mining industry. Such challenges are related to the variability of the mining industry and lack of reliable water data. Also, a consistent approach for water risk management is missing, as the industry is complex, its interaction with the environment is multifaceted and the water risks are uncertain and cumulative over the years.

The research strategy of this study is based on the case study research method. The case of interest in this study is the SERENE project. It is a project aiming at bringing a new water quantity and quality management system (WQQM) to the mining industry. The solution is an internet of industrial things (IIoT) based technical application platform. The software is integrated in online sensor measurements which enables real-time monitoring of the water balance of a mining site. The customer segment for the WQQM solution is the minerals and processing industry. The research methodology used in this study is qualitative content analysis. The empirical data for the research was collected through interviews. In addition, the empirical data includes data which is produced within the SERENE project. The analysis of the empirical data is carried out through the qualitative content analysis.

The study reveals that water management is an essential part of the mining industry's risk assessment especially in water scarce regions, where the allocation of water resources is crucial for the other local stakeholders. Four water related risks of the mining industry were identified which the interviewees described to occur in water scarce regions. The identified risks were a tailings dam breakage, shortfall of water, flood on the mine site and contamination of process water and dischargeable water. Also an essential identified factor impacting on these water related risks was the tightening environmental legislation. The central findings of this thesis are formulated into the following five propositions. 1. The risks of the mining industry are multidimensional. Proposition 2. The most relevant environmental water risks in water scarce regions are the shortfall of water and contamination of water. Proposition 3. A proactive consideration of the long-term risks of the mining industry is preparation for business activity threats. Proposition 4. Desired solutions for the prevailing environmental water management risks in the mining industry are solutions that enable the recycling of water such as the WQQM solution. On a practical level, the findings indicate that a data driven approach to water risk management in the mining industry is recommended. In terms of future research, it is suggested that the research would be longitudinal and focused on water risk management in a certain country as water risks depend on the location of operations.

Keywords: Mining industry, water, water scarcity, environment, risks, risk management

The originality of this thesis has been checked using the Turnitin OriginalityCheck service

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1 INTRODUCTION

1.1 Background of the study

Water crises are one of the main global risks in terms both the likelihood and impact. Such risks are polluted drinking water, floods, shortage of water and overused groundwater resources. (World Economic Forum, 2018.) Risks related to the future water demand and water supply do not seem to align in the future, which seems to increase the pressure towards the water supply and allocation (Organisation for Economic Co-operation and Development, 2015). Therefore, one of the greatest challenges of our society is meeting the increasing needs for freshwater resources while treating ecosystems in a sustainable way (Larsen, Hoffman, Luthi, Trudder & Maurer, 2016). The challenges ahead are relevant for industries that use water in their production (Fujimori, Hanasaki & Masui, 2017). The water use of the mining industry is not high compared to other industries, but most of the mining operations are in water scarce regions, where the water consumption can be high from the local perspective (Kemp, Bond, Franks & Cote, 2010). Therefore, to achieve the acceptance of local communities, mining companies need to use their water in a way that doesn't cause damage to the environment or society (Wessman, Salmi, Kohl, Kinnunen, Saarivuori & Mroueh, 2014).

The environmental circumstances vary in different mining operations as it is a worldwide industry. Therefore, risks related to mining operations range depending on the location of a certain mine site (Wolkersdorfer & Bowell, 2004; Northey et al., 2017). Most of the mining operations are located in regions where the water supply is challenging (Northey et al., 2017). Therefore, the mining industry has many challenges related to water management (Kohl, Wessberg, Kauppi, Myllyoja & Wessman-Jääskeläinen, 2013; Northey, Mudd, Saarivuori, Wessman-Jääskeläinen, & Haque, 2016; Frederiksen, 2018). Issues within water management have been recognized in the mining industry as water is an important resource of its operations. The risk assessment is a crucial part of mining operations since especially the water infrastructure, balance and quality can have many impacts on the environment and nature. (Wolkersdorfer et al., 2004.)

There's an existing need for further research on water related risks in the mining industry for the following reasons. The research on the sustainable development in the metals and mining industry has increased and there are many studies on different sustainability initiatives of the industry. (Hilson & Murck, 2000.) The studies highlight the controversiality of the sustainability in the mining industry as it can have negative environmental and social impacts (Kapelus, 2002; Jenkins, 2004; Dashwood, 2012; Frederiksen, 2018). As a response to the criticism, mining companies have taken social and environmental aspects as part of their strategies for recent decades (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018).

In addition, risk management in the mining industry has developed during the last three decades into a direction in which the mining companies observe risks on many levels as part of the strategy, not only from a certain perspective (Boatright, 2011). The industry has expanded in the recent decades and the ore grades are lower which has led into more difficult and complex production processes (Mudd, 2010). The complexity is also related to the societal and climate change and technological challenges in the mining industry. It is suggested that the complexity of the industry should be considered in the risk assessment and there's a need for new approaches on risk management. (Domingues, Baptista & Diogo, 2017.) However, the previous research has mainly focused on individual mining sites and their cumulative impacts. The assessment of individual mining operations doesn't provide the big picture of possible impacts of risks of different stakeholders. (Franks, Brereton & Moran, 2012.)

As a response to the prevailing water risks, mining companies have begun to initiate strategies that support sustainable water management, and have realized that there's a link between the water scarcity and the environment around the mining operations (Wolkersdorfer & Howell, 2004; Northey et al., 2017). However, there's a lack of understanding of the impacts of the water risks because there's a lack of data of the water use in the production chain in the mining industry (Kunz & Moran, 2016). In addition, the accuracy of water related data in the corporate sustainability reports has been criticised for not considering the local water context or geographical characteristics of a certain mining site (Fonseca et al., 2014). The water footprint has been suggested to address this issue which can also support the shift towards an environmentally friendly production.

Though, there's still a lack of research on the application of the water footprint model in the mining industry due to the complexity and dynamic character of the industry. (Northey et al., 2016.) As result of the changed atmosphere, the legal compliance and environmental regulations are insufficient to meet the needs of a society and avoid business threats such as conflicts and risks. The study of Prno & Slocombe (2012) emphasizes the need for further research on the social license to operate in the mining industry which is often operating in complex and dynamic environments. Bridge (2004) suggests that there has been a transformation in the mining industry and the social license to operate has become an important factor to comply with besides the legality and regulations.

This research has been carried out as part of the SERENE project, which is funded by the European Institute of Innovation and Technology. There are nine partners within the project and this Master's thesis is a commission for Outotec which is one of the project partners. SERENE is a project aiming at bringing a new water quantity and quality management system (WQQM) to the mining industry. The solution is an IIoT based technical application platform. The software is integrated in online sensor measurements which enables a real-time monitoring of the water balance of a mining site. The customer segment for the WQQM solution is the minerals and processing industry. There are also other studies and deliverables which are conducted by the project partners. The research strategy of this study is a case-study as it focuses on the SERENE project. The primary research data was collected by the author by conducting expert interviews. In addition, other materials provided by the SERENE project partners are used in this study as a secondary research data.

This thesis aims to find out what kind of water related risks the mining and metals industry has in water scarce areas. From the mining industry's perspective, it is important to acknowledge the difference between water positive and water negative regions since the local environment defines the context of the potential risks. Therefore, it is suggested that the location is considered in risk management. This study is focused on examining the water negative regions. Therefore, the water risk management approaches in countries such as Australia and Chile are highlighted as they are countries where the mining is a major industry. After identifying the water related risks in water scarce regions, the

research will continue by an analysis of the SERENE project approach. The analysis focuses on how the new technology such as the WQQM solution can mitigate identified water risks.

1.2 Research problem and questions

This thesis examines water risk management in the mining industry in water scarce regions. The aim is to increase understanding of the current issues within the mining industry concerning the water use, and assess risk management from the sustainability perspective. The objective is to bring the previous research and expert interviews together and identify existing issues with water management. The research is conducted as part of the SERENE project which is a real-life project aiming to bring a new water balance system to the market, and the study involves the examination of the WQQM solution which has been commercialized within the project.

The research questions are the following ones:

“What kind of water related environmental risks does the mining industry have in water scarce areas?”

“How can new sustainable water solutions mitigate water risks in the mining industry?”

The first question attempts to address the existing water risks in the mining industry by focusing on water scarce regions. The focus of this study is in dry regions which do not have much water in use for example for drinking, sanitation or industrial processes. In those areas, the water scarcity is an issue which affects the mining operations and infrastructure requirements. In addition, those factors create risks concerning mines but also communities, ecosystems and the industry nearby. (Northey et al., 2016.) The second research question is focused on the SERENE project and the new water quality and quantity management system (WQQM) and its purpose is to mitigate the water related risks in the mining industry.

These research questions are addressed through expert interviews and data from the SERENE project. The interviews were conducted by the author and the interviewees were experts who had knowledge on mining industry's water related risks or water scarce areas. They were representing different stakeholders in order to have different perspectives on the researched subject. The research data is analysed by using the qualitative content analysis. The data analysed from the SERENE project was used to address the second research question as the new water quality and quantity management system was assessed. According the analysis, the first research question was addressed through indentifying the main water related risks in the mining industry in water scarce regions. In addition, characteristics of water related risks were described. The second research question was analysed as a continuum of the first research question and the identified water risks were assessed through analysing the SERENE project and the WQQM solution. Finally, conclusions of this study can be put together through these research questions on prevailing water risks of the mining industry in water scarce regions and the new technical solutions that can be potential for risk management in the mining industry.

1.3 Research process

The research process was developed in an iterative way which is common for a qualitative study. This study follows the abductive research process, which means that the research doesn't follow a linear way, but the process is moving adaptably in different phases of the study. (Eriksson & Kovalainen, 2008.) Although there is no process defined beforehand, some of the research stages can be identified. Those stages are explained in this chapter.

At the beginning of the research process, in November 2018, a kick-off meeting was held with VTT which is one of the partners of the SERENE project. A relevant research subject was planned together within the project. After defining the initial research problem, the author continued the research process by familiarizing herself with the topic and the issue of the water use in the mining industry. The author had meetings with some of the interviewed experts before the actual interviews, to create a deeper understanding of the issue. The discussed themes concerned mainly the water use in the mining industry and how water positive and water negative regions differ from the mining industry's

perspective. Previous research was read of the issue of the water scarcity to gain a deeper understanding of the topic that was chosen as a focus of the research to form a perception of what has been already researched about the topic.

The next phase was to create the research plan where the initial structure of the thesis was created, and the research questions were formed in December 2018. At this phase, the research method was decided. A meeting was held where the research plan was discussed together with supervisors of Outotec and the university to make sure that the research plan is suitable from both perspectives. At this phase, the experts for the interviews were selected and contacted to schedule the interviews. The interviews were conducted between January and March 2019. The recordings of the interviews were transcribed and processed for the content analysis. The content analysis was carried out in March and April 2019, but as typical for a qualitative study, the research process was dynamic, and the author went back to writing the theoretical framework, as the empirical data and the interviews emphasized the focus of the study and helped to frame the theory part. In May and at the beginning of June the findings were finalized, and the conclusions were written by having the empirical data and theoretical framework as a basis. At this stage the author returned to the theoretical framework again and refined the final thesis as a whole.

1.4 Structure of the thesis

The structure of the thesis is the following: the first chapter describes the issue and its importance by presenting what kind of impacts water scarcity has and how this study is linked to the previous research on the subject. In addition, the research problem and questions are presented, integral definitions are defined, and finally the research structure and process are explained. The second chapter contains the theoretical background, including the theory explanation of water scarcity by shedding light on the previous research on the topic. The second chapter includes also a description of the mining industry especially in water scarce areas and the link between the water use of the mining industry and regions where water scarcity emerges. The second chapter includes the consideration of future scenarios on water scarcity and its relation to the mining industry in water scarce regions.

The purpose is to bring these theory insights as a background context for the empirical part of the study. The theoretical review of the second chapter is linked to the content analysis by analysing the empirical research material and its relation to the theoretical review on the water issues. The linkages between the theoretical discussion and the empirical expert interview material are identified by carrying out a content analysis on how water related risks occur in the mining industry in water scarce regions. Lastly, the chapter describes prospects for the future of how water scarcity will evolve and what kind of impacts it will have from the mining industry's perspective.

The final third chapter of the study comprises the findings which examine the empirical analysis. In the beginning of the chapter, there's an introduction of the research method which is the qualitative content analysis. Then the third chapter consists of the introduction of the SERENE project and demonstration of the WQQM solution. The chapter continues by an analysis of the interviews. The aim of the analysis was to answer the research questions by identifying environmental water risks which emerge in water scarce regions. The second research question was examined by assessing the WQQM solution provided by the case SERENE and its approach to the risks identified from the interviews. Finally, four propositions are formed from the analysis.

2 MINING INDUSTRY'S RISKS IN WATER SCARCE REGIONS

2.1 Mining industry and water scarcity

2.1.1 Mining industry and corporate responsibility

The history of modern mining operations is considered to begin already in the 14th century. The mining industry has enabled societies to develop and today it ensures us the modern life. It has been an essential driver of the development of the economy and civilized world. It has led us to be dependent on the metals and mineral resources nowadays. (Darling, 2011, 3-4.) However, there has been a widespread criticism of the mining industry. In the history, it has had a poor reputation due to operating in regions with a lack of social legitimacy and damaging the local area in order to gain benefit from the valuable resources in the region. (Jenkins, 2004.) There has been a growing pressure from local non-government organizations, communities and legal obligations which have pushed the mining companies to respond to the demand for corporate responsibility activities (Trebeck, 2008). Despite the undertaken improvements, mining companies have still received a critical reputation of trying to create a false image of their corporate social responsibility (CSR) activities and companies have been accused of greenwashing their actions even though their business operations are still having negative social and environmental impacts (Hamann & Kapelius, 2004).

In the beginning of the mining industry, most of the mines located in developed countries such as U.S. and Canada, whereas nowadays the trend is that Latin America, Africa, Australia and Chile are the leading countries in the exploitation expenditure (Darling, 2011, 3-4). Hence, the mining industry has a unique character in what comes to the location of its operations. The operations' geological circumstances depend on the location of minerals and metal resources, which can create restrictions. There is a variety of different geological conditions and technological solutions in mine sites around the globe. (Wessman et al., 2014.) There are also differences in the hydrology and water use contexts in different mining locations (Northey, Lopez, Haque, Mudd & Yellishetty,

2018). Because of the dynamic environmental conditions of different mining sites, tailored technical solutions are often required to suit to the local context (Kunz & Moran, 2016).

The mining and metals industry has been a controversial topic from the sustainability perspective (Dashwood, 2012; Frederiksen, 2018). It has confronted a lot of criticism for not considering the environmental and social impacts of mining operations (Kapelus, 2002; Jenkins, 2004). Darling (2011) claims that the criticism towards the mining industry is a consequence of the oblivious of development of technology, which is actually much more environmentally friendly and safer today than before. Mining companies have improved their activities to become more accepted in terms of environmental and social concerns. However, Mudd (2010) suggests that the sustainable mining can be perceived as a paradox, as the mining industry is interacting with finite resources for which the consumption of resources is working as an incentive, which leads to a higher pressure of using the finite natural resources. Yet, the study of Mudd (2010) reminds that the sustainability in the mining industry is a very complex field that requires research in the field of technology and economics and examining the environmental and social perspectives. Therefore, the sustainability of the mining industry cannot be defined in a simple way.

As a result of the criticism the mining industry has run up against it can be noted that mining companies have taken social and environmental aspects as part of their strategies for recent decades. They have also adopted the corporate social responsibility (CSR) reporting in which they report on the environmental and social aspects of their operations. (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018.) Also, Parsons, Lacey & Moffat (2014) describe that concepts that address environmental and social impacts of organizations such as corporate social responsibility initiatives are a consequence of the greater recognition of the company's impacts on its environment especially in the mining industry. Mining companies have used the Global Reporting Initiative (GRI) reporting framework for the CSR reporting, which has been criticized by researchers for not being an effective framework for the industry. The information has been claimed to be unreliable and misleading. The proposed approach for a more effective reporting would include consideration of undeveloped measuring methods and reporting in the industry

especially on a site-specific level. (Fonseca, McAllister, Fitzpatrick, 2014.) The shift towards the corporate responsibility has involved mining companies taking better account of the stakeholders through engagement and management of relationships with them (Kemp & Owen, 2013).

Nevertheless, it hasn't been simple to change the prevailing image, because there are numerous acts of negligence in the history of mining and metals industry (Frederiksen, 2018). In addition, Kemp & Owen (2013) argue that the corporate responsibility development in the mining industry has created confusion as there's no established framework for the corporate responsibility work as the industry doesn't yet comprehend the demands for corporate responsibility initiatives. Therefore, there's a need for innovations which clarify the role of corporate responsibility functions' role in mining companies' organizational operations as value adding functions. The contention of the corporate responsibility role affects also the decision making, which can lead into a situation that the stakeholder demand is not fulfilled.

2.1.2. Social license to operate

Nowadays many mining industry's stakeholders are expecting mining companies to pay attention to the local communities. The public perception of the mining industry has been one of the main challenges for the mining companies to success. (Zhang et al., 2015.) Therefore, the engagement with local communities is important for mining companies in terms of maintaining the local acceptance of mining operations. Today there's a widespread recognition in the mining industry for concepting the so-called social license. (Parsons et al., 2014.) or the social license to operate (SLO) which addresses the social acceptance of mining. The term social license to operate has been acquired worldwide by the mining industry and it has become an integral concept in the mining business (Zhang et al., 2015). According to Prno & Slocombe (2012), the sustainability paradigm in the mining industry has strengthened the requirements of local communities. This shift has led into criticality of the acceptance of local communities as they have become a major actor of the governance.

By achieving the social license to operate, a mining company can minimize the likelihood of possible social risks such as conflicts. Conflicts are not only social risks, but they usually have negative economic consequences. (Prno & Slocombe, 2012.) Parson et al. (2014) claims that a company's legitimacy can be put at risk due to the non-acceptance of the mining activities. The non-acceptance can be the result of a negative public trust which can be influenced by stakeholders' actions such as a boycott or legal issues. The social license to operate depends also on the local context. However, the social license to operate comprises different factors which ensure the engagement with the locals. Such factors that have an impact on the public acceptance of the mining industry can be fairness of distribution and procedures and confidence in the governance. (Zhang et al., 2015.) Zhang et. al, (2015) suggest that the factors impacting on the social license to operate are impacts on the social infrastructure, contact quantity and quality with community members and procedural fairness. Together those factors impact on the trust of the local community and when managed well they can lead to the acceptance and approval of the mining activities. Nevertheless, the increasing requirements of local communities address further the need for research on the SLO. There's not enough understanding on which governance models are suitable for different contexts of social, political and economic circumstances. (Prno & Slocombe, 2012.)

Moran & Kunz (2014) describe that in order to achieve sustainable operations, there should be all licenses to operate, which means that when investing in new solutions, internal and external stakeholders' views are considered with the outcome. Dare, Schirmer & Vanclay (2014) suggest that contrary to the general assumption of the single license achieved by the company through the community engagement, the social license should be understood as many licenses that are achieved on many levels in a society. Then, it is considered as a continuum of social licenses which press for the identification of successful engagement techniques in achieving many social licenses. Therefore, the social license is important for the long-term success, and managing the social acceptance can advance the adaptation in changes in the business environment (Vanclay, 2012).

2.1.3 Water use in the mining industry

Water resource management is linked to the wellbeing of societies and therefore there should be a broad perspective in water management and in the systems and measurements used to assess it. Hence, when managing water resources, the economic, social and environmental impacts need to be considered in the decision making. The mining industry interacts with water in the processes, waste disposal and dewatering. (Godfrey & Chalmers, 2012.) The amount of water resources and hydrological circumstances vary in different regions (Hoekstra, Mekonnen, Chapagain, Mathews, Richter, 2012; Northey et al., 2017; Castro et al., 2018). Most mine sites are in regions where hydrological changes are probable and where the water resources and water supply are limited (Northey et al., 2017). The mines also cause engineered changes in hydrological systems as mining operations drastically change sites' topographical and hydrological conditions in the long run (Northey et al., 2016).

Regulations, especially environmental and water permits restrict water management in the mining industry (Frederiksen, 2018). Because mining operations are complex and site specific, and water resources depend on the location, the assessment of a certain mining operation needs to be done on a case by case basis. Therefore, when assessing a certain mining project, consideration of local water context is needed. In addition, the amount of water used in a process depends highly on the base metal and quality of ore. (Northey et al., 2017.) There are several assessment tools that have been developed to measure the water use in the mining industry. Such assessment tools are water footprint, and life cycle assessment tools which can be used to assess a certain mine site. (Northey et al., 2016)

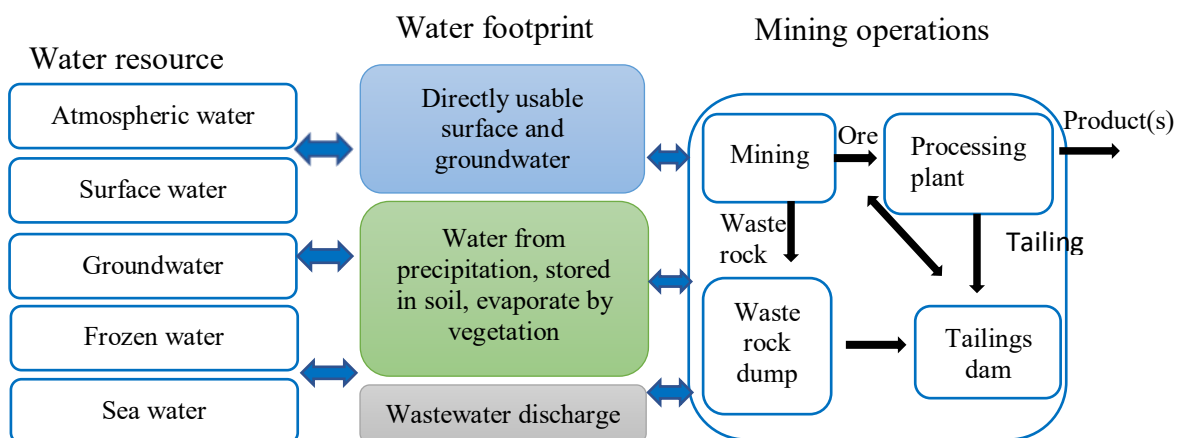


Figure 1. Water flows on a mine site presented hypothetically (Adapted from Northey et al., 2016)

As presented in Figure 1, the mining industry's water use varies depending on the water resource type as listed under the water resources part (Northey et al., 2016). Water is present at different stages of a mining project and therefore the life cycle assessment can be applied to the water footprint analysis (Zhou, Gong, Wang & Feng, 2015). The part which describes the water footprint in Figure 1, refers to the water footprint concept and its blue, green and grey water grouping. Blue water is water from the surface and groundwater, green water is water from the precipitation, soil, evaporation and vegetation and grey water is wastewater. (Mekonnen & Hoekstra, 2011; Northey et al., 2016.) The mining operations' part of Figure 1 shows different phases of mining operations which interact with water resources (Northey et al., 2016).

There are some established terms for water accounting and assessing the water balance of a mine site. The input refers to the volume of water that is received to the mine site operations. The output means the volume of water that is discharged from the mine site. The store is a facility where water is held. Raw water refers to pure water that is taken in the site and not used previously in the operations. Otherwise, water that has been used in some operations before, is called worked water. (Cote, Cummings, Moran, Ringwood, 2009.) The water balance is a concept which covers the whole use of water on the mine site, covering the water system and water account systems (Kunz & Moran, 2016).

The following Figure 2 describes the representation of the water balance of a mining site (Saari, 2017). It consists of water inputs; fresh water and clean water, which can be gathered from rainfall, runoff, water with feed ore and aquifer inflows gathered from an open cut and underground mine. On the other hand, water outputs consist of evaporation, discharge to surface and groundwater, entrainment in tailings and miscellaneous losses. Water can be stored in ponds and dams which can consist of different water qualities such as raw water or recycled process water. (Northey et al., 2016.) Figure 2 represents only the operational water balance of a mining site including its connections to the hydrological water cycle, whereas the surrounding community and environment around the operations are not included (Kunz & Moran, 2016).

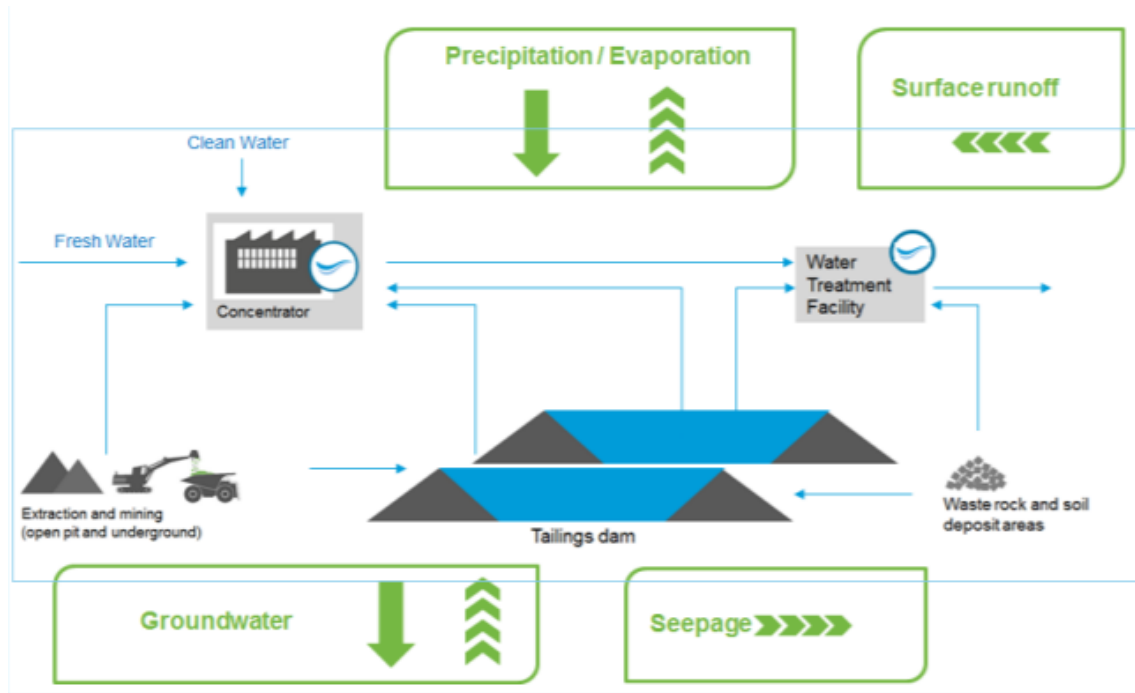


Figure 2. Visualization describing the water balance of a mine site (Saari, 2017)

The water balance can be defined as follows: “The water balance is an accounting process where flow and chemistry values are assigned to each of the individual water sources identified in the water-management plan.” (Botz, Mudder & Akcil, 2005, 26). The consumption of water and water sources are considered in the water balance. The water balance is not only related to the quantity of water, but also to the water quality. Depending on the water source, it might be pumped, cooled, or treated so that it would meet the required water quality. (Gunson, Klein, Veiga & Dunbar, 2010.) The water balance in mining operations can be defined as water positive or water negative depending on the mine site’s access to water. The water balance is positive when water (e.g. water from the rainfalls or melt water) tends to accumulate in the site’s water system, resulting in a need to discharge the excess of water out of the water system to the environment. Contrary to that, water negative operations have a net loss of water resulting in a need to continually supply water from external water sources to the water system. (Northey et al., 2017.) Kunz & Moran (2016) claim that the accuracy of the water balance is important for the decision making when making water related investments as it can affect risk management and the economic performance.

Kunz & Moran (2016) suggest that employees responsible for water management are usually aware of the water use in different processes in a certain department, but there's a lack of understanding of what the water quality and quantity impacts are in the production chain. However, Northey et al. (2016) discuss that the water footprint method can provide a solution to the issue of the insufficiency of water related data through its ability to standardization. In addition, there's an increased demand for standardization as the end-consumers prioritize eco-labeled products. An accurate inventory data of mining operations enabled through water footprint methods can support the accuracy of eco-labelling schemes. Thus, it can result in an increased consideration of environmental impacts and selecting environmentally friendly materials and sourcing. However, Northey et al. (2016) suggest, that there's an existing need for development of standardization for the water use in the mining industry. By developing standards, it would be possible to compare the water use to other water intense industries. However, the water related data is often included in the sustainability reporting practices of mining companies, but it has been criticized for not providing information of the local water context or other site-specific geographical data. The data could be more reliable if the reporting would be developed to provide information about the water quality or sources. (Fonseca et al., 2014.)

2.1.4 Defining water scarcity

Different phenomena can cause water scarcity. There are natural reasons which cause water scarcity but also human induced causes. Moreover, these together can result in a situation of insufficient amount of water resources. (Pereira, Cordery, Iacovides, 2002.) Through the human history, there have been different kinds of changes in the economical, technological and demographical development. It has led humans to impact on the environment around them. The development of societies has changed the environment; the food and energy production and urbanization are drivers of changes that have accelerated the human induced impacts on the water quality and quantity. (Huang et al., 2017.)

Water scarcity is a growing concern globally and the topic has been in discussion for many years. The research on water resources has also concerned the global warming and

how different water related challenges can impact on the societies, ecosystems and water management. (Huang, et al., 2017.) Yet, there's still not enough information of how water scarcity has developed through the history. However, researchers have developed several methods to assess water scarcity. Therefore, there are some established terms that describe the water resources and scarcity. Initially, water scarcity is a general term established to describe the issue of an insufficient amount of water which can be described by using concepts called water shortage or water stress. The water shortage is a situation in which the available water resources don't meet human needs. The water stress is a concept for analyzing the relation between the population and water consumption. (Kummu et al., 2016.)

Table 1. Difference between the water stress and water shortage (Adapted from Kummu et al., 2016)

Water scarcity	
Water stress	Water shortage
Impact of high water use on the water availability	A situation where there is not enough local water to meet human needs

The research on water scarcity has developed from 1980s when the link between the population growth and growing need for water resources was recognized. The industrialization was also identified as a driver of water scarcity. Falkemark, Lundqvist & Widstrand (1989) have developed a water stress index (WSI) which is an indicator that describes the regional water availability. Concepts of water scarcity and water stress were established for further research. However, the water stress index has been criticized for overestimating impacts of the water use in the mining industry (Northey et al., 2018). The withdrawal-to-availability ratio (WTA) was developed afterwards. WTA is a water scarcity measurement method which measures the ratio of the annual withdrawal to the annual resources. Yet, it has been argued that there's a need for integrated models which would include different water sources and water quality. Also, socio-economic impacts and adaptability to the national scale are desired. (Wheater & Evans, 2009.)

Figure 3 describes the issue of competition for water. The cubes represent one flow of 1 million m^3 per year available in terrestrial water systems. The dots represent the

individuals meaning that one dot includes 100 individuals who have a need for freshwater resources. It indicates that the larger the population is, the stronger the competition for water resources is. The problems within water management are limited when the population is below 100 persons, with 100-600 persons there occur general water management problems, with 100-600 persons a water stress occur, with 600-1000 persons chronic water scarcity occurs and with 1000-2000 persons and when the limit of 2000 persons is exceeded, the water capability is not manageable. (Falkenmark, Lundqvist & Widstrand 1989.)

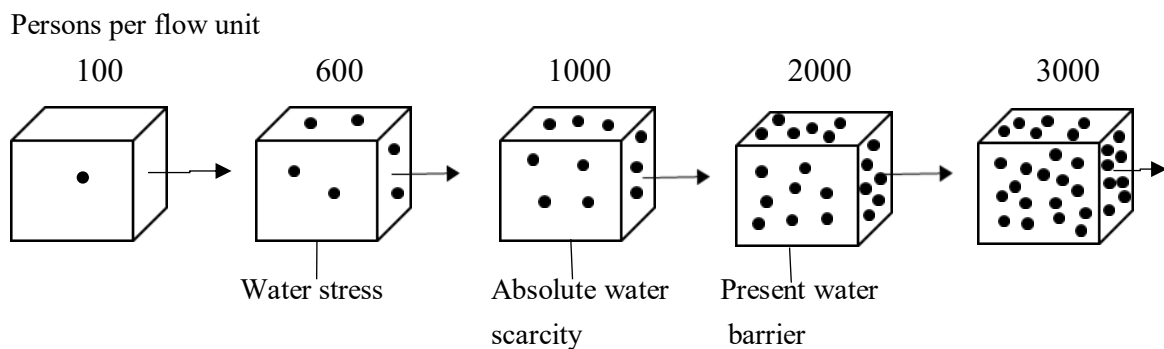


Figure 3. Visualization of different levels of water competition (Adapted from Falkenmark et al., 1989)

The study of Flörke et al. (2013) shows that the population growth and economic growth has led to an increased global domestic water use. WaterGAP3 model of the study concluded that the water use has increased continuously since 1950. Although the development of technology and changes in the behavior have had their impacts, the results show that there has been only a moderate increase between years 1970-2000. Nevertheless, the domestic water use increased after the stagnation period. This period can be a result of the increased industrial water use in growing economies while the industrial water use has decreased in most developed countries. Wada and Bierkens (2014) have also studied the global water use in 1960-2010 by using the blue water sustainability index. Even though the availability of water has been higher because of high precipitation rates, the global water consumption has increased since 1990. The study indicates that there's a growing trend of non-sustainable water consumption. Their study shows that the use of non-sustainable surface water and groundwater resources has

increased by thirty percent. They suggest that the consumption of water will increase in the future.

There is a popular theory of the water circulation which describes that there's a certain amount of water circulating continuously on earth and the amount of water in the cycle doesn't change (Falkenmark & Lannerstad 2005). However, the water research is still focusing on the issue of water demand and consequences related to the demand problems. The connection between water resources and social, human induced changes in aquatic systems has been recognized in the research. The consumption of water resources has led into a situation in which the theory of the water circulation doesn't totally apply anymore. It means that earth doesn't control the total amount of water resources. Globally recognized changes in aquatic systems have changed the use of water but also affected earth system processes in which water or related causes take part. (Maybeck, 2003.) Rijsberman (2006) questions the concept of water scarcity on a global level, by doubting if water is a scarce resource in the physical sense, rather the demand of it. Yet, this approach points out that water is scarce in a physical sense in arid regions with a high population such as Central and West Asia and North Africa.

Nowadays, there's a widespread consensus among water researchers that the pressure to meet the demand for freshwater resources is growing and a threat exists that it will worsen in the future (Hanasaki et al., 2013; Veldkamp, Wada, Aerts & Ward, 2016; Damkjaer & Taylor, 2017; Cui et al., 2018; Castro et al., 2018). As Falkenmark et al. (1989) theory visualized in the picture of water competition showed, the population growth is a driver of change which is a threat for people who are dependent on it. The population growth leads into a higher demand for food, water and products. It will affect the social and economic stability and inevitably the environment. (Cosgrove & Loucks, 2015.) The study of Hoekstra et al. (2012) suggests that there are 2,7 billion people who are experiencing severe water scarcity every year for at least one month. Rijsberman (2006) argues that a region can be called water scarce when people living in a water scarce region suffer from a lack of water for a long-lasting period. The authors of the Intergovernmental Panel on Climate Change (IPCC) (2014) report claim that in terms of the water availability, demand and pollution, there are serious threats to the water security which affect 80% of world's population today (Jiménez et al., 2014).

The water footprint approach is a widely used tool for analyzing the water use. There are specific international standard principles for the water footprinting, which are based on the lifecycle assessment method and assesses the environmental impacts of the water use. (International Organization for Standardization [ISO] 14046, 2014.) It involves a geographical consideration, identifies the quantity and quality of water and hydrological changes (ISO 14046, 2014). Blue water, green water and grey water classifications are also related to the water footprint method which is widely used to assess the impacts of the water use (Falkenmark et al., 2007). It is not clear to assess water scarcity as it is a complex resource because of its dynamic character (Mekonnen & Hoekstra, 2011). Falkenmark et al. (2007) have categorized blue water scarcity into “apparent” and “real”. Meaning that apparent water scarcity is a situation in which there’s a lot of water available, but it is not used efficiently and a large amount of it is lost because of the wasteful treatment. Real water scarcity means a situation in which there’s lack of precipitation or there’s a high amount of population living in an area with a limited availability of water.

2.1.5 Water scarce regions

The problem with water scarcity is worldwide, yet water resources are not evenly located on earth. It means that the issues affected by water scarcity emerge differently in various continents. (Hoekstra et al., 2012; Castro et al., 2018.) The amount of water resources varies in different regions and therefore some regions can be qualified as water scarce regions. Water scarcity can be seen as a situation that there’s not physically enough water in a certain region. Otherwise, water scarcity can be caused by the high size of the population, which creates higher competition for freshwater resource and increases the pressure for the demand of water. (Falkenmark et al., 2007.) As visualized in Figure 3, the population size has inevitable consequences on the availability of freshwater resources (Falkenmark et al., 1989).

The economic development of a society often leads to an increased water use. In that situation, aquatic systems of a region work by the source of water resources. It can be used for different purposes such as for agriculture, domestic and industrial uses. It also

leads into a situation in which there's a higher competition and pressure among different stakeholders. Sometimes a basin needs to be closed if otherwise it would mean an overuse of water. These situations can be managed by using different methods such as the reallocation, demand management or inter-basin transfers. Yet, groundwater or surface water exploitations and unevenly shared water resources emerge in those regions. (Falkenmark & Molden, 2008.) When looking back to the history of water scarce regions, it can be expected that water scarcity is a barrier for the economic development. Conflicts might occur in water scarce regions when there is a high competition of water among different sectors due to the socio-economic development. A limited availability of water resources is becoming an evident barrier for socio-economic growth. The issue affects also the environmental prosperity in dry regions. (Zhou, Deng, Wu, 2017.)

An essential factor in the water resource allocation is that the water consumption is controlled by legal authorities. Usage rights are often used to allocate water resources. Outright ownerships are not as usual even though some countries have them for groundwater. The water allocation regimes are differing by country. Water resources have also a different legal basis applied to them. For example, Australia's water resources are owned by the Crown whereas in the United Kingdom water is not "owned" as such, but the land adjacent to it or overlying it can be. Policies concerning the allocation of water resources can prescribe who have the permission to use water, how it is used and how much it can be used and what amount of water should be returned and in what quality. (OECD, 2015.) Policy regulations have a markable role in the water use which can have cumulative impacts on the development of the water allocation and water use. New policy regulations can work as a driver for new water saving technologies and investments. (Flörke et al., 2013.)

The climate is crucial for the availability of freshwater resources because the rainfall provides the freshwater resources that can be used. Water evaporation rates are high in regions where water scarcity emerges. Therefore, low latitude regions confront water scarcity, because of the evaporation caused by high temperature. Lack of soil water can cause poverty and hunger which is typical for arid regions. (Falkenmark et al., 2007.) There are already countries where there is water stress because of the increased competition on freshwater resources. The issue is evident in Australia's Murray Darling

basin, middle East, southern Africa, southern America and Northern India and in some parts of the central US. (Perry, Steduto, Allen & Burt, 2009.)

The authors of IPCC report (2018) recognize projected impacts of a regional climate change. Higher temperature is linked to a higher spatial variability of precipitation which can mean that precipitation will reduce in higher latitudes and in parts of the tropic. Moreover, it has been recognized that there are many regions where the warming exceeds the global annual mean warming. It is caused by the insufficiency of water, which is linked to an outcome in which there is not enough water for the evaporative cooling. The thermal inertia doesn't work as effectively as in the oceans which leads into higher temperature. The reduction of precipitation in subtropical heights is the largest climate change projection in terms of precipitation reductions. Monsoonal circulations can be caused by higher precipitation rates and enhanced moisture convergence. The study of Christensen et al. (2007) claim that the developed modelling and empirical statistical downscaling and knowledge of physical processes has led into a higher reliability of regional climate projections. Those climate projections provide information about the impacts of climate change. Regional impacts of climate change are projected to an impact in three different sections; temperature, precipitation and extremes.

2.2 Mining industry's risks related to water scarcity

2.2.1 Risk management in the mining industry

The risk assessment in the mining industry has developed during the last three decades into a direction in which mining companies observe risks on many levels, not only from a certain perspective. Therefore, strategic risk management has taken a place and risk management has become an essential part of the corporate governance. (Boatright, 2011.) Flaus (2013) suggests that the perception of risk is depending on the viewpoint – for that reason, risks are often classified into different risk categories. Vose (2008) discusses that risks are usually classified into different categories, such as project acceptance,

communication, environmental, financial, strategic or legal risks. By doing so, it can be easier to assess various perspectives of a certain project.

The complexity of the mining industry doesn't only refer to complex environmental circumstances. There are also external economic changes in the minerals and metal market that are complex and dynamic. (Kumar & Rathore, 2015.) Nevertheless, Galvin (2017) notes that uncertainty is related to risks in general. Therefore, there should be an ability to manage the risks to prevent and mitigate them so that the consequences would be acceptable. Mineral commodity prices are changing and effects of volatility in the market affect the global demand. There are new regulations which require more actions from mining companies, though regulations are country specific. Especially environmental regulations are increasing. These changes together are creating uncertainty for mining companies to enable a cost-effective business. (Kumar & Rathore, 2015.) The uncertainty can be related to the trends of the modern mining industry. Mudd (2010) claims that the modern mining industry confronts pressure as the industry-wide trends are related to major fundamental changes. The changes are related to lower ore grades, increased production and its relation to economic resources and increased amount of waste rock which will complicate the rehabilitation. Thus, these trends impact on the consumption of water, energy and chemicals. In addition, climate change will impact on the mining industry and cause risks related to the local hydrology, water quality and infrastructure. (Northey et al., 2016.)

Flaus (2013) discusses that uncertainty describes risks as their consequences and possibility to occur are situation-specific. It means that the potential of hazard event is uncertain and might occur in the future, causing damage. There are external and internal impacts that can cause uncertainty to an organization. To meet the objectives and to support the strategic guideline setting and decision making, an organization must manage risks. Risk management can involve different components in an organization. Those components can contain a framework, principles or processes of risk management to help an organization to achieve its risk management objectives. Thus, risk management can be described as an iterative process, as risk management can be modified to fit into a certain organization. (Risk management standards of International Organization for Standardization [ISO] 31000, 2018.) ISO 31000 (2018) series provide risk management

guidelines regarding principles, framework and process. By using the standards, a company can identify possible opportunities, threats and use its resources effectively in any kind of risk.

Different techniques can be used in the risk identification phase. There can be listed different failures, machines or different process stages as well especially when analyzing a certain manufacturing plant. (Vose, 2008.) Nevertheless, the risk assessment in the mining industry is many times based on the available data. It might be difficult to assess risks in case there is not enough data available or the data is not accurate. (Verma & Chaudhri, 2014.) Domingues et al. (2017) suggest that the complexity of the mining industry should be considered in risk management of the industry. Bijanska & Wodarski (2013) describe that the mining industry's complex characteristics are due to different technologies that are used in the production processes. Domingues et al. (2017) claim that the current risk management methods do not cover all the possible risks that might affect the mining industry's current challenges. Such challenges can be the human capital, climate change and new technology. Therefore, there should be new approaches on risk management in the industry. There can be a specific risk assessment tool for complex systems in the mining sector. (Domingues et al., 2017.)

2.2.2 Water risk management in the mining industry

There's a continuous need of water imports to meet the process requirements on water negative sites while water positive sites need to discharge water. Especially water negative operations can be challenging, since the water availability might be allocated to agriculture, forestry or environmental flows. (Northey et al., 2017.) Water is usually stored in dams or ponds on mining sites. Especially in water scarce regions, it can be difficult to maintain the amount of water resources due to high evaporation. Then, the evaporation can be an issue to which mines are trying to find solutions. The solutions used for this purpose have been covers, shading and floating solar panels to prevent the evaporation. (Northey et al., 2016.)

Over the past decade, there has been a significant development in measuring the impacts of the water use. The benefit of the life cycle assessment method is that it considers the local water context including the hydrology and other regional characteristics. Therefore, there's only a limited knowledge of what is the role of a specific regional impact when assessing the water use in the mining industry. (Northey, Lopez, Haque, Mudd & Yellishetty, 2018.) However, even though the methods have developed in recent years, there is still a lack of research on water risk management in the mining industry. The gap in the research can be due to the limitations related to adopting methods such as the life cycle assessment or water footprinting. (Northey et al., 2016.) Furthermore, the consideration of the water balance and hydrology are significant for water risk management (Northey et al., 2016).

Mining is a risky industry that has been recognized widely. There are several processes included in the ore extraction which means that there are many complexities which can cause risks in terms of the human health and environment. (Verma & Chaudhri, 2014.) Water risks in the mining industry are highly site specific as there are different mining sites across the world. Therefore, water risks depend on the local environment, hydrology context which is the reason for risks being site-specific. The risks can be perceived by local communities, mining companies, ecosystems and industry. The water risks of mining operations can be related to accessibility of water supply, flooding, dam collapses and water discharges. (Kunz & Moran, 2016.)

Kunz and Moran (2016) claim that the water-related risks of mining operations can be divided into two. Firstly, dryness, which refers to an insufficient amount of water resources to meet the production demand. Secondly, wetness, meaning a too high volume of water which requires discharging it. Risks are present at every stage of the lifecycle of a mine. There are examples of risks that have realized and caused enormous damage and in the worst case this can have devastating consequences which affect the environment, social health and safety, reputation and economic performance. (Galvin, 2017.)

One of the major risks in the mining industry is the risk of a tailings dam breakage, also called a tailings dam failure. A dam breakage is often caused by weather conditions, such

as unusual rain or snow melt. It can be also caused by for example poor maintenance, lack of proper dam safety inspections, design errors, sub-standard dam construction or geologic instability. (Rico, Benito, Salgueiro, D'íez-Herrero & Pereira, 2007.) In addition, the impacts of climate change are desired to be considered when assessing the risk of tailings dam breakages as changing weather events may have additional risk factors for management of a tailings dam. There has been a worrying number of tailings dam accidents in the last decades. (Azam & Li. 2010.) Nevertheless, Northey et al. (2016) criticizes that the inventory data for water foot printing doesn't include data of tailings dam breakages even though the impacts of them can be catastrophic for the environment and society.

Aqueduct Water Risk Atlas is an organization that measures and maps water risks. It has its own category for mining related water risks. They have different risk categories for the physical risk quantity, physical risk quality and regulatory and reputational risk. The overall water risk consists of 60,2% of physical risk quantity, 4,9% physical risk quality and 35% regulatory and reputational risk. (Gassert, Landis, Luck, Reig & Shiao 2014.) The first risk category refers to the water quantity risk. Kunz and Moran, (2016) suggest that one of water related risks is dryness, which refers to the insufficient amount of water for the production. In Table 2, the baseline water stress, drought severity and groundwater stress are dryness related situations. On the other hand, flood occurrence and upstream storage related risks can be related to a too high volume of water. However, the inter-annual variability and seasonal variability impact on these water quantity risks. Water quality risks can be related to input waters returned to the facility which can impact on the production. In addition, the water quality can also refer to dischargeable output water, which can be important for the local people and environment. The last section, regulatory and reputational risk refers to the image impacts of a mining company. (Gassert et al., 2014.)

Table 2. Mining related water risks (Adapted from Gassert et al. 2014)

Mining related water risks			
Risk category	Physical risk: quantity	Physical risk quality	Regulatory & reputational risk
consists of	<ul style="list-style-type: none"> • Baseline water stress • Inter-annual variability • Seasonal variability • Flood occurrence • Drought severity • Upstream storage • Groundwater stress 	<ul style="list-style-type: none"> • Return flow ratio • Upstream protected land 	<ul style="list-style-type: none"> • Media coverage • Access to water • Threatened amphibians
weight distribution	60,2%	4,9%	35%

There have been many different approaches to water management in the mining industry to mitigate water related risks. The water footprint has been a potential model to assess the water use and risks related thereto in the industry as it has been developed and become useful in addition to the life cycle assessment method. There are still many challenges in the industry due to the complexity and variability of the industry. In addition, there's a lack of research on how these models can be used within the industry. (Northey et al., 2016.)

2.2.3 Water scarcity risks in the mining industry

The mining industry is dependent on water although it is not the major consumer of water. For example, in 2010-2011 the mining sector used 4,1% of the total water consumption in Australia. (Northey & Haque, 2013.) However, the local environment is crucial for the mining industry and the amount of water consumption can be high from the local perspective. Many mining companies operate in areas where the local people are very

poor and vulnerable. In addition, most of the mine sites are in water scarce regions where the pressure to water access is high. (Northey et al., 2017.) To achieve the social license to operate, the mining industry has an interest to use their water in a way that doesn't cause any harm to the environment or society (Wessman et al., 2014). Radosavljević and Radosavljević (2009) claim that there are many environmental disruptions identified within the mining industry. In terms of environmental risks, the mining industry has impacts on a variety of environmental factors which are inevitably related to social impacts. They conclude in their study that the risk assessment of a mine should consider air, water and land use in terms of environmental impacts.

Global and regional risks are not isolated. Global qualitative drivers can be on the background when assessing possible events that might occur on a regional scale (Döll & Vassolo, 2004). As described, water risks have been noted on a global scale – yet the risk examination is different on a regional scale. When assessing water scarcity risks on a smaller scale, there are much more specific factors to consider. Individual river basins can be assessed by examining the health of the ecosystem, which is a systematic analysis of river condition by assessing different environmental metrics. (Davies et al., 2010.) There's a clear link between societies' activities and interactions of water ecosystems. The life of societies and landscape depends on water. However, the water quality and natural cycle of water can be harmed by societal activities. There's a risk that it can affect the sustainability of the biosphere. Environmental risks of societal activities can impact on natural hydrological processes such as evapotranspiration, runoff generation, groundwater recharge and water quality genesis. (Falkenmark, 2016.)

An empirical study conducted by Kohl et al. (2013) contains a roadmap for a sustainable and acceptable mining industry. It consists of assessing the stakeholder collaboration and acceptance of mining on the global and regional scale until year 2030. The main drivers of risk management identified in the study were political goals, especially environmental regulations, social license to operate, shareholder requirements and the growing importance of the mining industry because of our modern life needs (Kohl et al., 2013). However, when examining risks of the mining industry from the perspective of a certain mine site or region, the risks can be linked to water quality risks, tailings dam breakages, pollution, rehabilitation and post-closure of the mine site (Northey et al., 2016).

2.3 Future prospects of the water scarcity risk in the mining

The availability of water is expected to worsen due to climate change as it will lead into a situation in which the water resources will be even more unevenly located (Perry et al., 2009). The authors of IPCC report (2018) claim that there's a medium confidence that global warming has major impacts on water related challenges in the future. If global warming will not be kept under control, it can be expected that the water stress will increase in some countries. It is also possible that extreme weather conditions such as droughts and precipitation deficits will increase if global warming continues.

Perry et al. (2009) suggest that countries that are water scarce today, will have even more shortage of water due to the higher temperature and dryness caused by it. When the globe is getting warmer, the water related circumstances will differ in regions. There will be an increased amount of precipitation in high latitudes and equatorial pacific, while the precipitation will decrease in mid-latitude and dry regions. It is also very likely that precipitations in mid-latitude areas and wet tropical regions will become more extreme. Monsoon precipitations will become more intense as well. In addition, the authors of the report claim that there will be new risks that are caused by climate change and accelerate risks that already exist. (Jiménez et al., 2014.) Erkin and Hoekstra (2014) have studied water footprint scenarios for 2050 and identified main drivers of change in the future. The study is a global analysis, but these drivers can influence on a local level as well. The first driver of change is population growth which has a huge impact on future scenarios regarding the amount of demand for products and services. This concerns especially food as it is vital for human life (IPCC, 2018). The increasing need for water in the food production leads into a higher demand for other uses of water such as industries' water use (Erkin & Hoekstra, 2014).

The research on water related future drivers are usually examining global megatrends and socio-economic changes that will impact on freshwater resources (Döll & Vassolo, 2004). Such upcoming changes in the previous research are population growth, economic growth (Döll & Vassolo, 2004), changes in agriculture (Erkin & Hoekstra, 2014), global warming (Cui et al., 2018), technological development and the way of trading and consuming (Döll

& Vassolo, 2004). The IPCC report (2018) has recognized the following assumptions regarded to future trends: population, consumption of goods and services, economic growth, behavior and technology. As the mining industry operates in an environment that affects physical systems and biological systems of the nature, it also affects the societies around it meaning that the mining industry can have impacts on the human health and activities. The mining industry enables the development of societies and urban life. Therefore, these global drivers and megatrends will have indirect and direct impacts on the mining industry. (Ercin & Hoekstra, 2014.)

It has been emphasized that there's not enough strategic thinking focusing on mine sites, which has led into a decreased productivity. Therefore, there's need for end-to-end solutions focusing on optimizing the whole business which would break the silos which cause a so-called integration gap in the mining industry. The integration is possible through using technology and data. (Mitchell et al., 2017.) In addition, the concept of circular economy has been in the public discussion recently and it has been suggested for the wastewater thinking as well. Meaning that the idea of closing the loop by reusing resources could be used in the wastewater solution. The processing of wastewater can have many positive impacts, such as food and energy security and climate change mitigation. It can be possible to carry out water solutions that support the circular economy idea by using the latest technology. (UN, 2017.)

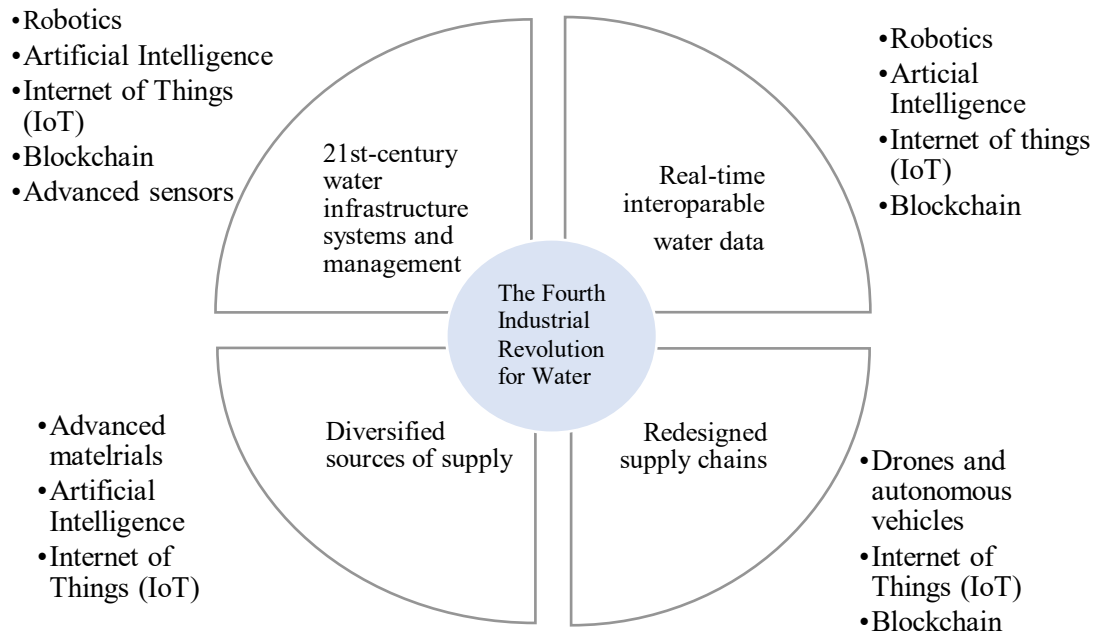


Figure 4. The fourth industrial revolution game-changers for water and sanitation (Adapted from World Economic Forum, 2018)

Figure 4 describes the possibilities of different technologies of the 4th industrial revolution, which is the current wave of the technological development. Figure 4 shows that the latest technological development has brought new solutions, such as robotics, artificial intelligence, internet of things and blockchain. These new solutions enable that water related issues and risks can be managed better by getting real-time interoperable water data, redesigning supply chains to be more efficient, diversified sources of supply and using 21-century water infrastructure systems and management. (World Economic Forum, 2018). The WQQM solution works by internet of things, artificial intelligence and advanced sensors which makes its functions possible. When reflecting to Figure 4, the WQQM solution can provide real-time interoperable water data of the mine site, and it can be possible to update the mine site water systems to 21st-century water infrastructure systems and management as the solutions are enabling features that have not been in the industry before. It helps also to redesign the water use at the mine site to enhance better water balance and to meet the tightening environmental regulations. (Serene proposal, 2017.)

2.4 Synthesis of the theory

This synthesis summarizes the theoretical framework of this thesis in which the mining industry's water risks are in the focus. The mining industry has enabled the economic development by providing metals and mineral resources for the market. (Darling, 2011, 3-4.) Nevertheless, the industry has confronted criticism for only gaining economic benefit from the limited natural resources and not considering the local communities or environment (Kapelus, 2002; Jenkins, 2004). Mining companies have responded to the stakeholders' demands for corporate responsibility activities and nowadays social and environmental issues are part of many mining company's strategy and CSR reporting has been adopted by the industry (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018). However, the corporate responsibility of the industry has been claimed to create confusion as its role is unclear (Kemp & Owen, 2013). Regardless of the mining industry's strategic actions and reporting efforts, the companies still confront criticism and conflicts that pose risks for the industry. The research criticizes that the information in the sustainability reporting has been unreliable and misleading because there's a lack of data on site-specific measurements (Fonseca, McAllister & Fitzpatrick, 2014).

However, it is worth noticing that from the risk management perspective, the mining and metals industry is unique as the processing technologies and operational conditions vary significantly due to variability of mineralogy in different geographical locations (Wessman et al., 2014). Risk management is even further complicated as the local hydrology and water use context varies by mining site (Northey et al., 2018). To limit the scope of this thesis to a reasonable scale, only the water risks and their mitigation in water scarce regions have been investigated. This limitation does not, however, diminish the value of the study, as most of the mining sites are located in water scarce regions where the water availability is poor (Northey et al., 2017).

Water scarcity can be defined as a concept that describes the issue of the insufficient amount of water. Water scarcity is a global concern which has been recognized to be one of the major global challenges. (Falkenmark et al., 1989; Hanasaki et al., 2013; Wada et al., 2016; Damkjaer & Taylor, 2017; Cui et al., 2018; Castro et al., 2018; World Economic

Forum, 2018.) However, water is not evenly located on earth and water resources vary in different regions. Especially the Southern hemisphere is suffering from the limited availability of freshwater resources (Wessman et al., 2014). Although the mining industry is not the largest consumer of water compared to other industries, it can be a major consumer of water on the local context, especially in water scarce regions where the water availability is poor (Nothey et al., 2017). This creates pressure as the water access should be distributed fairly among the different stakeholders. To get the social license to operate, which refers to the acceptance of local communities, the mining operations should access, use and discharge water carefully, so that there would not be any harm to the environment or society. (Wessman et al., 2014.)

The study of Freitas and Magrini (2013) discusses water management in mining operations. They have created an approach for including environmental aspects into the decision making and risk management practices. The approach is represented in Figure 5. Even though Figure 5 is a simplified representation, it clearly illustrates the fact that environmental risks are multidimensional by nature. Therefore, they should be managed holistically, to cover not only the typical ecological risks but also the economical and image dimensions the environmental risks may have. This approach suits well for considering mining industry's risks in water scarce regions that has been in the focus of the theoretical contribution of this thesis.

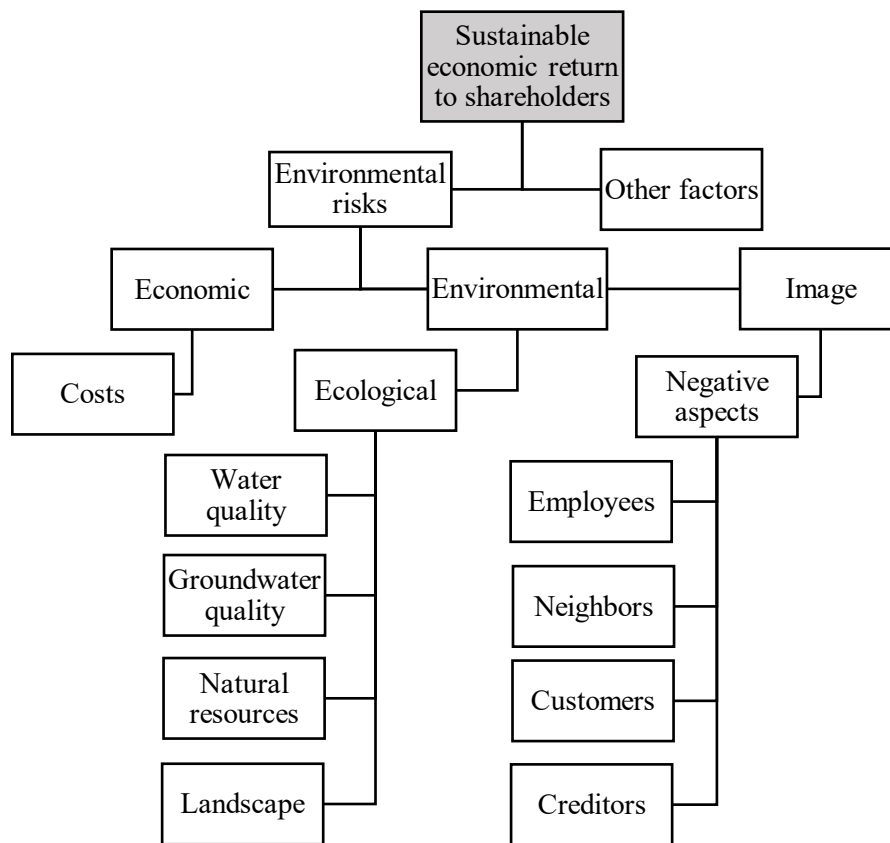


Figure 5. Sustainable water management decision-making process (Adapted from Freitas & Magrini, 2013)

Frederiksen (2018) has adopted a different approach to mining industry's risks by categorizing the risks into three different categories: operational, reputational and political/regulatory risks. However, if aiming to a sustainable economic return to shareholders, environmental risk management should be holistic. Holistic risk management means that there are many aspects for stakeholders to be considered when managing water related risks in the mining industry (Boatright, 2011; Godfrey & Chalmers, 2012; Northey et al., 2017). Nevertheless, irrespective of the decision-making and risk management approach selected, water risks of the complex mining industry operating in dynamic social, economic, political and legal conditions should be done on a case by case basis by considering different risk perspectives and the local water context (Kunz & Moran, 2016).

A further analysis of Figure 5 indicates that the economic side of risks is represented to be linked to costs. Costs can refer to different activities related to the water use. For example, in a water scarce region, the costs can be due to the loss of production which can lead into a lower revenue or the costs can be related to fees for the water use. The environmental impacts of environmental risks represented in the Figure can be related to the water quality and quantity, groundwater, natural resources or landscape. (Freitas & Magrini 2013.) The water quality can refer to discharged water or process water. Groundwater can be damaged due to the pollution induced by the mining operations. Also the overuse of groundwater may easily limit other stakeholders' access to water, causing conflicts with consequent issues with reputation and image. (Kemp et al., 2010.)

Sometimes, water can be pumped, cooled or treated to meet the desired water quality (Gunson et al., 2010). However, these actions may have big cost implications that generate additional economic risks. Also, there seems to be a lack of understanding of the water quality impacts in the production chain. (Kunz & Moran, 2016). Suggested solutions to this are more accurate data, the water footprint method and life cycle assessment approach (Northey et al., 2016). It is also desired to increase the water quality related data in sustainability reports (Fonseca et al., 2014). Natural resources in Figure 5 can refer to the impacts on limited water resources which can lead into depletion of water resources in a region. In addition, the local landscape is used for the mining operations and therefore it is used and modified for a tailings dam, for instance. Environmental risks can also impact on the image of a mining company. The image can impact on the attitude of the employees, neighbors, customers and creditors (Freitas & Magrini, 2013.) Especially local communities which can be employees or neighbors of the mining industry operating in the area need to be recognized and managed well in order to achieve the social license to operate so that a risk of conflict can be avoided. (Bridge 2004; Prno & Slocombe, 2012; Northey et al., 2016.) It is worth emphasizing that water risk management in the mining industry is nowadays considered on many levels and as a part of strategy (Boatright, 2011).

One of the central observations is that environmental and water risks are not isolated from the social or economic risks. Rather they are all connected to each other. Risks can always be divided into different risk categories to clarify the assessment of risk likelihood,

impacts and mitigation measures. However, when a mining company manages its environmental risks, it needs to adopt a holistic approach to risk management to be able to mitigate all kind of risks. Besides risk management, sustainability strategies have become an important part of the mining industry. Despite the criticism towards sustainable development of the industry, it is noteworthy that water risk management and sustainability strategies can support each other. Holistic water risk management with proper risk mitigation measures can lead into a better sustainability performance and on the other hand sustainability activities can enhance water risk management.

3 METHODOLOGY

3.1 Qualitative research

When deciding on the research method which is to be used in the research, it is important to consider that it suits well for solving the research problem (Eriksson & Kovalainen 2008; Hirsjärvi & Hurme, 34, 2011). The qualitative research method was chosen for this study because it has been used on business research to focus on complex business phenomena (Eriksson & Kovalainen, 2008). The context of this study is the mining industry which is a complex industry and the complexity is even more prominent in water scarce areas. The qualitative research is a research method that aims at understanding a certain subject. Results of the qualitative research depend on the subjective knowledge; what kind of meanings are given to the research subject and what tools are used in the research. Therefore, theory has an important role in the research to support the subjective perceptions. (Tuomi & Sarajärvi, 2018.) As subjective perceptions are present, hidden assumptions are always included in the research. People are used to experience different things and phenomena which leads to thoughts that are led by habits. (Hirsjärvi, Remes & Sajavaara, 2009, 129-130.) The empirical data of this study is based on experts' views on the topic, thus subjective perceptions are present (Flick, 16.-17, 2009). However, different viewpoints and practices are considered in the qualitative research which was carried out by interviewing different stakeholders for this research.

Research models are often divided into deduction and induction, which are models that explain the research process. When the research is following the deduction, it means that the theory is the most important source of information and the research process begins linearly from theory to the empirical study. Contrary to that, the induction refers to research which is derived throughout the research process from empirical research to the theoretical outcome. In addition, the research can follow a research process called abduction, which combines these two methods in an iterative way, combining the theoretical and empirical knowledge at different stages of the research process. This research is following abduction as the process is not going linear way from theory to

empirical research or the other way, rather the process is iteratively based on using both at different phases of the research process. (Eriksson & Kovalainen, 2008.)

3.2 Research strategy

3.2.1 Case study

The research strategy of this study is based on the case study research method. A case study is collecting detailed information on a specific case or from a small population of cases which are in relation. The first research question tries to describe a certain phenomenon which is common for a case study research. The second research question focuses on a specific case, SERENE project and its features, as for is typical for a case study. (Hirsjärvi et al., 134, 2009.) Many data sources of the SERENE project were available for this study as SERENE is a large project including different data from the project partners. It is important to define the limits of the research data to be used for the study, in order to reach in-depth research findings (Hirsjärvi & Hurme, 135, 2011). The data provided by the project partners was used to create understanding of the WQQM solution. One research can contain a variety of different empirical data. It is important to design the data used in the study. In addition, there are several ways to gather and document the data which is to be analyzed for the research. (Eriksson & Kovalainen, 2008.)

A case study means that the research will focus on a certain real-life case in its meaningful context and the purpose of this thesis is to shine light on the case itself and produce new information about the project SERENE. The data for a case study can be qualitative and quantitative. (Mills, Durepos & Wiebe, 2010.) A case study is a research method which includes a clear link between the case study examined and research questions, because the aim is to understand and solve a certain issue. Therefore, a case study contains description of the case and what is the new knowledge it can provide by studying it. The case study describes this research well, since the SERENE project has been developed to improve the water balance of the mining industry, thereby the project itself has been established to solve the issue. (Eriksson et al., 2008.)

3.2.2 Case SERENE

This Master's Thesis is a case study as part of a project called SERENE. It is a project targeting on bringing a new water quantity and quality management system (WQQM) to the market. SERENE is a project which has 9 partners and VTT is the lead partner. Outotec Oyj is a Finnish exchange-listed company which develops and tailors leading technology solutions and life cycle services. They have two business units; Minerals Processing and Metals and Energy and Water. Sustainability is in the core of Outotec values and its vision is to “provide technology solutions for the sustainable use of Earth's natural resources”. (Outotec website, 2019.)

Outotec's new water solution WQQM is a water balance solution which enables the mining industry to monitor and predict an individual mining site's water balance in real time. The solution makes it possible because it connects monitoring stations, device management, data collection, data modelling, simulation and visualization to cloud. The technology is possible because the data sources are integrated in cloud services which is possible due to an internet of things application platform. There are distributed process measurement sensors on the mining site which are technically suitable and validated for the environmental conditions. This technology helps the mining industry to monitor an individual mining site in real-time. It enables also a better planning and control of the water management operations, as the solution is able to provide a short-term forecasts for the water volumes and quality. (SERENE proposal, 2017.) “The solution aims to improve dynamic, predictive water balance management capability; reduce water related risks; and enable increased water recycling with decreased impacts on production performance” (EIT RawMaterials, 2018).

The solution works by the industrial internet of things (IIoT) which enables the optimization and visualization of the production. The industrial internet of things (IIoT) is a digital concept that enables the shift towards a smart and autonomous industrial production. IIoT makes its possible since there's a real time connection between people, machines and objects. (Beier et al. 2018.) IIoT enables that the mine site's water balance can be assessed easily by the real-time information and forecasts provided by the system.

Therefore, the water balance of the ore processing facilities can meet the legal and sustainability requirements by optimizing the water use.

The solution monitors the critical positions of the mine site's water cycle to build up a holistic view of the site's water balance. As examined, external hydrological circumstances impact on the site's water balance. The WQQM solution integrates the plant's dynamic production to the hydrological water cycle. It creates visibility and enables predictivity of the water balance. The solution provides history, status, forecast and scenario reports. By creating the possibility to this kind of visibility, the solution helps the mining industry in the decision-making in operational situations. The real-time data enhances the possibility to use water resources more effectively through providing information for planning the water use. A long-term benefit of the solution is that by providing a better understanding of the water balance of the site, it enables an educated information for planning of new investments. As the environmental permits are tough and getting tougher, it is important for mines to get better control of how they manage their water. This is where the WQQM system starts to provide added value. (Serene proposal, 2017.) The Serene proposal (2017, 4) describes the SERENE project on a practical level:

- 1) Demonstrates the performance of autonomous, wireless, low-cost monitoring stations equipped with state-of-art IIoT technologies to facilitate water quality and quantity monitoring at large mining sites
- 2) Demonstrates the performance of IoT application platform to serve as a basis for real-time water balance management and reporting services,
- 3) Demonstrates the performance of dynamic, predictive water balance modelling software under dynamic production conditions,
- 4) Quantifies and validates the value-add and risk reduction generated by the solution.

The following Figure describes the WQQM system's functionality. The software provides the data to the mining company, then the WQQM data is stored in the Outotec cloud and to Outotec's water management experts. The data provides visibility of the operations' water streams which are assessed by the experts of Outotec and the water management performance is analyzed in more detail and reported. By doing so, they can

suggest the customer (a mining company) to do improvements to its water management. The circle continues and the performance is being assessed continuously. (Di Noi & Ciroth, 2019.)



Figure 6. Functionality of the WQQM solution (Saari, 2017)

3.3 Data collection

The empirical data collected for this study consists of data collected through half structured interviews and data provided by the case SERENE project partners. Common for a half-structured interview, also known as half standardized interviews, is that the perspective of the interview structure is decided beforehand, but the order of the questions can change during the interview. It also means that the interviewer can ask additional questions during the interview. There are usually specific themes within the interview in which the questions are focused. Therefore, they can also be called theme interviews. (Hirsjärvi et al., 47, 2009.) In this research there were six different themes which were introduced to the interviewees before asking the questions.

The interviewed persons for this research are experts. The expert interviewees are usually employees of an organization who have a certain experience and knowledge of the researched subject (Mayring, 2000). The aim of using expert interviews can vary. The

aim of using expert knowledge in this study is related to the research problem; to collect information for getting a comprehensive view about the topic while studying another kind of method. Ten interviews were conducted in total. There were two respondents in two of the interviews. All the interviewees that participated in the interviews are presented in Table 3. This is the primary data collected by the author.

The data from the case SERENE project partners used in this study is internal and external data which has been created within the project. However, most of the data used for this study has been public and marked as a reference, in order to avoid sensitive information or lack of transparency in this study. The data consisted of the project proposal, presentations, websites and studies which have been done by the project partners. Also meetings with Outotec and VTT were held in order to understand the WQQM solution and its functions and to focus on the most essential risk management issues in this study. WQQM functions related to water risk management were examined specifically as this study focuses on water risk management in the mining industry. Therefore, the SERENE project's data used in this study is focused on the risk management solutions provided by the WQQM.

Table 3. Interviewees interviewed for this study

Interviewee	Background of the interviewee	Date	Type	Length
1	Technology Director, Minerals Processing	30.1.2019	Face-to-face meeting	1h 10min
2	Director Long Term Service Agreement, Regional Business Management	30.1.2019	Skype-meeting	55min
3	Member of board, The Finnish Association for Nature Conservation	4.2.2019	Phone- interview	1h 9min
4	Senior Researcher, Sustainable Development		Face-to-face meeting	42min
5	Senior Research Manager, Minerals Processing	7.2.2019	Face-to-face meeting	58min
6	Senior University Lecturer, Department of Built Environment	7.2.2019	Face-to-face meeting	41min
7	HSD Officer	11.2.2019	Skype-meeting	51min
8	Development Manager	11.2.2019	Skype-meeting	51min
9	Researcher, Department of Civil Engineering	12.2.2019	Skype-meeting	1h 12min
10	Sustainability Consultant	27.2.2019	Skype-meeting	58min
11	Centre for Economic Development, Transport and the Environment	19.3.2019	Skype-meeting	1h 33min
12	Centre for Economic Development, Transport and the Environment	19.3.2019	Skype-meeting	1h 33min

In addition, pre-meetings with some of the interviewed experts were held before the final interviews, in order to understand the water related issues within the mining industry. The pre-meetings helped to understand the SERENE project's targets and reasons for bringing such an innovation to the market. Open discussions with the experts were used as a basis when forming the research questions. The first meetings are used as an empirical evidence to support the material collected through the interviews. Yet, the empirical part of the study's main emphasis is in the information from the conducted interviews.

In order to understand the consequences and frequency of the risks which the interviewees described in the interview; a risk matrix was used in the interview. The risk matrix has five different levels of the consequences (negligible, minor, major, hazardous and catastrophic) and five different levels of the frequency (rare, unlikely, possible, likely, almost certain) of a certain risk. The risk matrix was shown to the interviewees during the interview when asking questions about the theme four of which concerns risks related to water scarce regions in the mining industry. The risk matrix and the interview structure can be found from the appendices to this study.

The interviewees were chosen so that they would represent different stakeholders and views. The selection was carried out purposefully so that the interviewees have different kinds of backgrounds so that the data collected would include different viewpoints on the subject. Therefore, the interviews include perceptions of Outotec internal employees, NGO's, university researchers and public experts. In addition, there were different nationalities among the interviewed people. This was noticeable from the data, in such a way that the interviewees' perceptions of risks highlighted different perspectives. For instance, the interviewees had higher knowledge of the relevant legislation from their own countries. However, the perception of risks also depends on which stakeholder perspective the interviewee is representing, the data implicates that different stakeholder interests can vary remarkably especially when examining the mining industry which has had problems with bad reputation.

3.4 Data analysis

The qualitative content analysis is an approach that suits well for analyzing qualitative data. This method was chosen for this study as it suits well for analyzing the researched phenomena and forms concepts to describe certain issues, which is done through an interview analysis in this study. (Elo & Kyngäs 2008.) The advantage of the method is that it is possible to make interpretations of a text and categorize them which enables to answer the research questions. The aim of this study is to create understanding of the mining industry in water scarce regions which is possible by using a content analysis through forming concepts of several expert perceptions on the subject. (Mayring, 2000.)

The analysis of the interviews began already during the interview process. During the interviews, the interviewer can begin the analysis by identifying if certain phenomena were discussed by many interviewees and if there were some cases that the interviewees brought up several times (Hirsjärvi & Hurme, 35, 2011). After the interviews were held, the recordings were transcribed. The data analysis process continued by coding the transcriptions. The coding means that the data is classified into certain categories (Hirsjärvi & Hurme, 2011).

The analyzed information from the transcribed interviews was not in a linearly structured order, rather the insights were found through coding the text into different types and categories. Yet, the purpose was to identify the interviewee's perceptions of the researched subject and research questions. For this reason, the coding of the interviews was done by examining the themes of the interviews which were connected to the research questions. During the first reading and coding of the text, there were certain themes identified, which were repeated in the research data. Such themes were difference between risk management issues in water positive and water negative regions, different risk categories and growing stakeholder pressure on water issues.

After coding the text, the research data was read second time so that it would be possible to form a wider picture of the research data, especially considering the research questions. The attention focused on how the interviewed experts define water risks in general so that it would form a basis of the analysis of the risks they discussed. Definitions of risks were

collected from the research data and the definitions were compared. The collection was done by highlighting parts of the text and writing them into different categories. The aim was to understand more complex characteristics of water scarcity risks in the mining industry. During the second read, there were new themes identified from the research data. Some parts of the research data were read many times to understand what the interviewee really meant by some matter.

After dividing and comparing the research data, the research data was read for several times more, to gain a deep understanding on different water related risks of the mining industry and the complexities that exist within water risk management. The focus was on water risk management, and different factors that have impact thereon were considered. Such factors were different stakeholders, risk categories and regulation. In order to understand the relation between these risk management perspectives, mind maps were formed, which helped in the research analysis. After forming the mind maps, the identified water risk factors were divided into different categories.

Qualitative research data can be coded into different categories. A categorization matrix was used as a tool in this study to divide identified categories into different sections. (Elo & Kyngäs, 2008.) As the researched topic of this study was recognized to be multidimensional, the research data was simplified through categorizing different risks into their own categories. However, when conducting a case study, the case examined needs to be generalized in order to identify the key issues of the case study. Otherwise, it wouldn't be possible to understand the case by a person who hasn't been involved in it. (Eriksson & Kovalainen, 2008.) This was taken into account and the categories presented in the matrix were deeper explained in the findings section before the matrix. Therefore, the categories summarize identified water risks.

The first column of the matrix, was formed to present different water risks which were identified from the research data. The identified water risks in the matrix are: tailings dam breakage, shortfall of water to the mine site, flood on the mine site and contamination of process water and dischargeable water. Then the identified risks were analyzed from the perspective of different dimensions which were chosen with the purpose that they would

summarize the most significant matters of different water risks which were discussed in the research data. The different categories are: characteristics on a water scarce region, stage of the mining project, propability, consequences, risk management issue, case SERENE solution and case SERENE impact. The dimensions were chosen with the purpose that they would summarize the most significant matters which were discussed in the research data. The final matrix is in chapter 4.3.2.

4 FINDINGS

4.1 Perceptions of the mining industry's risks of water scarce regions

The data implicates that there have been significant changes in water management in recent decades. The atmosphere has changed, and companies are expected to take part in the societal welfare by examining its impacts on the environment and local habitats on a social level. Thus, this development has enhanced companies' call for sustainable development activities and strategies to cope with these expectations. It has also increased the importance of strategic water risk management which supports the sustainability targets. The changed approach has increased the requirements of the mining industry's water use. The data analysis indicates that the approach should be wider and include different activities which support the sustainable development. Mining companies cannot focus only on their own business activities, but they should take a wider perspective of their operations and their impacts. The data indicates that mining companies are expected to examine their whole product value chain, which includes the consideration of environmental and social impacts in which risks have an important role.

There needs to be consideration of eco-efficiency, water risks, also social impacts should be examined and now there are different indicators, there's water footprint which I have worked for last ten years pretty intensively. So, assessing water and its impacts in the different stages of product value chain and it's totally different than we used to check, process emissions and nothing else. (Interviewee 5.)

4.1.1 Context of water scarcity in the mining industry

A matter that is emphasized in the whole data is the importance of considering the context of a mining project. The data analysis indicates that when examining water risks, the context of local water resources is a crucial factor. The regions can be divided into water positive or water negative according to the availability of water resources. Therefore, the risks of water positive and water negative regions should be distinguished and examined separately. The local environmental conditions were highlighted by the experts as it is

one of the essential parts of the mining industry. Also the competitive use of water resources by other stakeholders in the local society were discussed to be an important part of the local context.

So I guess the way we can kind of say risk in the mining industry really depends on the location, it depends on the local context, what's the climate in that location, have variables in climate weather is stable for a year and then also what other water uses surround the mine because it depends on the respective stakeholders what happens in a mine. (Interviewee 10.)

The experts highlighted that the local context was the regulation of the mining industry's water use. The regulation was a common factor that constitutes in the whole data through experts' views on the link between risks and regulations such as the legislation and permits. It was considered being an essential part of the context where a mine is located as it usually creates a framework for risk management.

It depends on which area the mine is, that can it work there as it wants or should it be very precise on some matter, is something demanded or prohibited completely. So, it's up to their legislation. (Interviewee 4.)

Although in some cases the locals might have the power to impact on the regulations and permits, it is also pointed out that lack of regulation is also a risk which creates uncertainty.

Of course, it is one risk, if there's no regulation at all. And it's also risk, if there is existing regulation but it is possible to deal yourself out of the situation by using money. (Interviewee 5.)

In addition, the local regulation and permits determine how the local water resources are allocated which brings the social perspective into focus, especially in water scarce regions which are lacking clean water resources. The location of a certain mine site can vary also

from the social point of view, meaning that some of the mine sites are closer to habitations and some are far away from towns or cities where people live. However, if focusing on water negative regions, there are some similarities considering risks of how much water resources there are to be allocated among different stakeholders. Experts described that the social point of view should be prioritized before other uses.

In general terms the dry areas are areas where you have water, but the water is limited resource and this limited resource must be used by different stakeholders correctly. So, for example, in one dry area you have probably water that may be used for domestic, for the people. and after that, you can go there and use it for industrial uses. but first you need to comply with the people that are living there. (interviewee 2.)

The issue of water scarcity was seen to be linked to global warming which is considered to enhance the issue of the inadequate amount of water resources. Climate aspects were assessed to be connected to water scarcity in terms of hydrological changes which seem to be concerning the areas which already suffer from water scarcity.

It is a climate question directly, so if potential evapotranspiration is higher than precipitation, then there's shortage of water on that area. So, there are historically big manners which have dry areas which are whether rest on surface water and then the river waters have competitors of course, from which the people are possibly the most critically important. (Interviewee 3.)

The concept of social license to operate is mentioned many times in the data. It is described to be related to the societal impacts of mining companies. The perception of the social licence to operate is connected to the access of water as the local community might influence on how the mining companies can get the access to local water resources. Thus, this is depending on the location of a mining site, whereas the social licence to operate is more relevant in regions where people are living near by the mine site. Therefore, the acceptance of local communities depends on how close the mine is to local habitations. The pressure coming from the locals is based on the power of local

communities on granting water licenses. The community acceptance is country specific and the interviewees described their own experiences in their home countries. There was a notable difference between the descriptions of different countries. For example, the interviewee described that in Australia, South America, U.S. and Mexico there have been cases where the local communities have the power to impact on water allocation.

I think one of the main problems they have is: community acceptance for the use of water and then also how that influences their access to water and how they can get access to water. So we say a lot of mines in Australia and South American countries and actually in U.S and Mexico as well, there's a lot of mines, but, essentially they don't get access to local water because the communities are so opposed to the government granting them water licenses. (Interviewee 9.)

However, contrary to what has been said above, in Chile the water allocation was described to be determined mostly by a third party. It indicates that the power to impact on the social risk of not having enough clean water resources is lower for the habitations in Chile. Achieving a social license to operate can be difficult, if the company doesn't participate in helping inhabitants voluntarily.

We have very particular law in Chile in terms of water allocation rights, so the rights of water usage are in third party hands. So, it was given to a third party which means that it is not any privatization of water use. That's why a city can have water even though the next door you have huge grape fields being irrigated and that's because those farmers have the water rights and the town hasn't got any. (Interviewee 10.)

Nevertheless, the findings indicate that there has been a lot of discussion and NGO activity about the issue. They suggest changing the law in a such way that the local people would be the priority in terms of water consumption. As a response to the pressure from the local people, mining companies have different kinds of approaches to get the social licence to operate. However, there seems to be a link between the community acceptance, compliance of environmental impacts and governmental decisions. Thus, there are many

stakeholder interests related to the water use of a mining company which makes it very complex business environment.

Today there's huge discussion to change the law and to change these private water rights (in Chile) because there's no preference for drinking water. But it's very difficult that the law is going to change of what you say, I mean if there's a political law in not to change it because there's a huge economic interest behind that. (Interviewee 10.)

Recently in Australia there have been a lot of protests against new coal mine developments. And a lot of these protests are actually related to the access to water. So, there have been lots of community challenges through the courts to contest how these mines comply with the environmental impact assessment processes. (Interviewee 9.)

The findings from the empirical analysis of the interview data show that the experts consider the concept of risk as multidimensional. The multidimensionality is due to the varying aspects of risks such as the stakeholder interest, company's approach, country regulation and environmental aspect of company actions. The different aspects of risks were considered from different stakeholder interests such as company interest, interest of local population, interest of non-governmental organisations and political interest. Many of the interviewees consider that managing an economic risk is on a high agenda for companies. Also, the risks were considered to belong into different categories such as environmental, social, economic or reputational risks. The quotation below is an example of the expert's perceptions of risks:

There are different kinds of risks, they can be pure environmental risks, then there can be social and economic risks which is very important. I think that a company considers automatically what is the economic risk. And there are reputation risks. If someone wants to assess risks, different levels need to be considered. (Interviewee 4.)

The multidimensionality of risks is also related to the impacts of risks. When a risk realises, it was considered to have possible impacts on different risk categories at the same time. A risk was seen to be a possible threat to many risk categories, meaning that a realized risk can have for example economic, social and environmental impacts at the same time. The risk assessment was seen as an important part of company's preparation for possible risks that can occur when carrying out its business activities. The multidimensionality of risk impacts was identified in such quotations as below:

I would say it's as we define it as an event that can occur and cause significant damage both to the environment and society and to the business itself. (Interviewee 10.)

Yet, the stakeholders may lay different emphasis on different risks categories. The stakeholder emphasis is related to the stakeholder interests which may vary among them. The power to impact on risks can be unevenly distributed among different stakeholders which can create an unequal set-up for risk management. It can be considered as a risk, if the risk is underrated by the company who has most of the power for its own interest. This can be a situation in which the company should be responsible for its risk assessment. For instance:

If it is fair (risk assessment), it should affect the planning in such a way that some project is left unrealised. If we can think that risks causing serious damage are present. I guess usually risks are underrated in a way, since the likelihood seems to be very low and then risks are taken. (Interviewee 6.)

Regulations are addressing the issue of unequal power distribution as they allocate the power for stakeholders by restricting the actions of companies. Yet, regulations are context specific as they vary in different countries. For instance, environmental impacts of a company's activities can be restricted by environmental permits. A company needs to comply with the restrictions imposed.

Also, environmental risks, there's a need for assessing environmental risk when applying for environmental permits. Then the environmental items are assessed. (Interviewee 7.)

To summarize, the location of a mining project is an important part of the risk assessment. There are mining operations globally in different regions and the local context can vary significantly among different regions. There are similarities among the mining operations in water scarce regions, as the scarcity of water resources creates certain kind of circumstances itself. Water scarcity is a restriction for companies operating in those regions. However, there are also many region-specific factors that may affect water risk management such as regulations, social acceptance and NGO activity. Therefore, many of the interviewed experts described that the risk assessment should be done case by case.

4.1.2 Water risks in the mining industry

A connecting factor in the water risk consideration is the difficulty of the impact assessment. As mentioned in the previous subchapter, the data indicates that risks are multidimensional due to different stakeholder perspectives and different risk categories. The same issue concerns water risks as they can be related to different risk categories and different stakeholder impacts. For instance, some risks were considered to impact negatively on the economic performance but not harming the environment at all. The quote below is an example of the difficulty of the risk assessment described by the experts.

Risk is a very fuzzy term. And actually, extremely difficult concerning risks related to water, if that's a financial risk for a company, so it's very hard to prologue on these things. And a lot of it is a reputational risk I would say. There are many risks like the risk of dam collapse but it's just very hard to qualify those risks. (Interviewee 10.)

In addition, the assessment of the possible impact was seen as a challenge for the mining industry due to the cumulative impacts. The assessment of cumulative impacts was

described to be difficult as the relation between the short-term and long-term effects is not simple to qualify. If a risk is being realized, its impacts can be very different in the short-term than its impacts in the long-term, as the impacts can cumulate in the long run. The cumulative impacts are especially related to the environmental aspect of water risks and substances which might have unexpected impacts on the environment in the long term.

The big issue is that it is very hard for us to classify, if something happens, so what is the short-term effect and what is the possible long-term effect. And usually the direct effect is under consideration, what happens at the moment and for example mine's waste waters, there's no large effect immediately. But they can have extremely large impact when it cumulates for ten years or fifty years for example. (Interviewee 1.)

However as described, a risk doesn't only impact on one risk category directly, but it can have impacts on many risk categories indirectly. The environmental damage of water risks can cumulate in the long run and have social impacts on the local habitats because the local waters can be vital for the local habitats. Therefore, risks that cause environmental damage to the local water resources, can cause significant disadvantage to the society. Water being a vital source for life, a risk of pollution can cause a situation in which the area changes to unliveable. This kind of social risk is described in the following quote:

Water is recreation area in Finland but for many it is the source of drinking and washing water and if it is polluted, it cannot be used anymore. Of course, if the fishing stock is damaged, it can be a significant source of nutrition. So, these are these kinds of social disadvantages, that the area is not viable anymore as there's no usable water or water for food. (Interviewee 4.)

A factor influencing the risk impact is the context of the water resources which are impacted by the risk. Water risks depend on the local water context as the risk impact depends on the dilution. The dilution is related to the cumulative impacts as the impacts

can be different in the short-term and long-term, as the water conditions and possible harmful substances change over time. These risks depend on the local water context, which may vary in regions. In regions which have a lot of water resources, the water can dilute much easier, while in regions where water is a scarce resource the concentration of harmful substances doesn't dilute so well.

Environmental risks are central, so as I said, there water concentrate a lot and also water which is discharged into the nature, has very different quality than here in the water positive area where water naturally dilutes through precipitation and for other reasons very much. (Interviewee 5.)

To summarize, the experts' perceptions of the concept of water risks in the mining industry are complex and they find them to belong in different risk categories. The data analysis indicates that especially the impacts of possible risks can be difficult to assess, as the short-term impact can cumulate in an unexpected way which can be hard to identify beforehand. The complexity is related to the stakeholders as well, as there can be many stakeholders within the mining industry to whom the interest may vary significantly. The power of the stakeholders is usually not evenly distributed which affects the consideration of some stakeholder interests. It can lead into a situation in which the interests of a certain stakeholder are not considered and the power to impact is in the hands of a stakeholder who may have differing interest behind its actions.

4.2 Identified risks of the mining industry in water scarce regions

It was possible to identify certain environmental risks from the empirical data by the content analysis process. They are different environmental risks, in generalized subclasses. The events are identified from the interviews, though they might not be distinguished from each other in the real-life accidents in the mining industry. This sorting is done to understand these different risks and their characteristics in the context of water scarce regions better.

Moreover, different stages of the mining process were pointed out by some of the interviewees when they described the risks of the mining industry in water scarce regions. Three main stages of a mining project were identified from the data. The stages are 1. development stage, 2. operation stage and 3. post-closure stage. The characteristics of risks at different operation stages is an important part of risk management. However, other stages can be named too, in which risk factors may emerge. For instance, the impacts on the ecosystem are relevant at the development stage and the effects of the operations on the local water quality can impact on the drinking water of locals. Whereas in the post-closure stage, the risk management performance is relevant which can be the mitigation of identified water risks through risk management measures such as monitoring of the water quality.

At the post-closure stage there's usually consideration of the impacts on landscape. The rehabilitation of the area is part of this phase as there can be long term risks occurring such as waste rock dumps in the area. In addition, as discussed in the previous subchapter, there are interlinks with the risks of different stages. For example, risks that don't as such realize during the operation stage, but instead accumulate during operation stage, may realize at some point during the late part of the operation stage or during the post-closure phase. For example water contaminants may accumulate slowly over the years in the pond system. Thus, this risk is related to the closure stage because when a company closes the operations, there can be million cubic meters of contaminated water that should be cleaned somehow. If the company has not prepared financially for this, or if the legislation does not require any monetary guarantees from the companies to secure the treatment, there's a huge environmental risk. These issues are impacting the whole mining industry image. In this way, different risk categories and impacts can be related to each other and managing one possible water risk can have broader risk management impacts at different stages of a mining project.

4.2.1 Tailings dam breakage

Based on the data analysis, the tailings dam breakage was one of the most mentioned individual water risks of the mining industry. The realised risks of tailings dam breakages

in the history have had an enormous impact on the mining industry as the consequences of these events have been large-scale as the impacts have caused damage to the environment, societies and economies. On a water scarce region, a tailings dam breakage can cause enormous environmental damage because a warm temperature causes high evaporation which can impact on concentrations due to the warm weather in those areas. However, the economic consequences can be hard to measure when it comes to the number of fatalities and destroyed nature. These events are rare, yet they have happened all over the world.

So, I guess water can be related to tailings dams so one of the major risks in the mining industry is the stability of tailings dams. This is something that would have a catastrophic influence but across industry it's fairly rare. So, something like a tailings dam as a result of water mismanagement would be something like a moderate risk for a lot of companies I would say. Obviously, accidents happen as we have seen for example recently in Brazil. There are examples all over the place. (Interviewee 9.)

During the writing process of this thesis, a major tailings dam breakage realized in Brazil. It was discussed in the interviews and it seemed to be an impulse to the topic. It shows that this research subject is topical as these events are present in the mining industry. The cumulative impacts were described to be related to this kind of extreme risk. Short-term risks can cumulate for many years, and the situation can be totally different in the long term when these kinds of unexpected situations can realise. Also the relation between long-term and short-term risk management was discussed to be crucial to consider. The quote is an example of how the interviewees described the recent dam breakage in Brazil.

There's a horrible example from Brazil. So, the risk frequency is extremely low, but the consequences are very terrible. And if it would not have been Vale, which is one of the world's biggest mining companies, it would have quit right away the company, it would have gone to bankrupt right away. And that's a small matter compared to the fact that 300 people are from lives. (Interviewee 1.)

These thoughts implicate about the importance of long-term risk management. The investment for risk management would be much smaller if there would be a better preparation for these kinds of situations when a catastrophic situation is let to happen by mismanagement of short-term risks. The worst case is that the short-term risks are let to cumulate in a long run which can cause a multiplied risk such as a dam breakage.

4.2.2 Shortfall of water on the mine site

The data analysis indicates that the shortfall of water is one of the risks which is frequent especially in water scarce regions. There are mining companies that face the risk of insufficient amount of water resources every year. Many of the interviewees described situations in which water has run low and the production has been shut down for a certain period. The shortfall of water can impact on the economic performance of a mining project due to the production loss as there's no water for the production processes. The stage of the development process in this case is the operation stage as the ongoing production is shut down.

So, there is the risk of shortfall of flow of water to the mine site, so if the mine runs out of water that I guess can lead to loss of production for long periods of time. A mine in New South Wales in Australia, a gold mine, owned by Newcrest, and there in 2006 they ran out of water, so they had to negotiate with the local government to get access to the towns water supply to keep the mine going, but they did have a loss of production. (Interviewee 9.)

To address the issue of the water shortage, many interviewed experts described recent water allocation issues in Chile, where they have begun to utilise seawater as a water resource for the production process. The barrier of using sea water is that there's a need for desalination. In addition, the use of sea water was described to be difficult and costly. A technical challenge is that seawater's salt can be a difficult substance for the pipes when the water is transported.

There is for instance in Chile where people are using sea water directly in water circuits and it's not really impacting the product recovery too much. So, it's one of those things, it depends a lot on the mineralogy of the well and the exact processes being used. But I guess the problem is, if you were to use sea water directly, you would get a lot of accumulation of salts in the circuit, so then if you are recycling your water too much, you actually get accumulation of these salts. (Interviewee 9.)

The water shortage can be a risk at the post-closure stage because the area should be restored. If the local water resources have been used for the production, there can be a situation in which the local water source dries out.

Then an environmental risk can be that there's shortage of water and the mine needs a lot of water, so the water source dries out. They simply take everything out there. So that is dangerous. (Interviewee 4.)

4.2.3 Flood on the mine site

The research data indicates that there's risk of flood on a water negative site, as there can be wet periods when the site can turn to water positive for a short period of time. Therefore, a water scarce mine might face a situation in which it has too much water stored in its tailings dam when the wet period begins. However, flood is a possible risk even though it is not very likely in a water scarce region compared to the water positive regions.

Water scarce regions, the frequency of a flooding is often times very rare. Or actually at the same time, water scarce regions mines will allow water to accumulate in the tailings dam, because they want to use that water later in the future. But then if they suddenly have a wet period come through, they might not actually be able to get rid of that water fast enough. (Interviewee 9.)

On the basis of the data, flooding in water scarce regions is described to be rare but it can occur unexpectedly, when the mine has no proper risk management to prepare for the situation of having heavy rain on the mine site which can cause the flood.

More frequent risks would be short-term flooding at mine sites like places such as Queensland in Australia, every few years we get all sorts of flooding over the pits and mines. (Interviewee 9.)

4.2.4 Contamination of water

The contamination of water was a risk which appeared widely in the research data. In a water scarce region, the impact of impurities can be much higher due to the concentration effects which can worsen the risk in those regions. The interviewees described the contamination of water through different risk events. For instance, spill of wastewater, also called acid mine drainage in the data, can damage the environment, contaminate drinking water of locals and cause economic loss. Acid mine drainage can have adverse impacts and be a major risk of contamination of the local waters and environment. In this situation, harmful substances are released accidentally to the nature and water is contaminated. Another side of contamination of water is its impacts on the production process. There can be a production loss and the quality of the product can suffer from the contaminated water.

Will there be things such as acid mine drainage that might get into water ways and cause significant ecological damage, will things like dust be managed appropriately on the mine site and will things like dust impact things such as local towns and things. (Interviewee 9.)

The data implicated that the contamination can be a risk even though there would not be any spill of wastewater in the mine in case water discharged by purpose contains unwanted substances. The consequences are dependent on the case, but in water negative regions the contamination is more likely to cause harm as the concentration does not dissolve very well if the amount of water is low in the waters which are contaminated.

The other one is contamination but not due to particular event but is cumulative contamination given the discharge of water with metals for example. So that's I would say in terms of frequency, so that's happening all the time because it's cumulative impact. I would say often. And the consequences really depend on the concentrations and the time when it happens. (Interviewee 10.)

The risk of contamination can be relevant at all stages when the local waters are affected by the mining project. The quality of water can be impacted from the beginning of the mining project to the post-closure stage due to the cumulative impacts. The cumulative impacts concern especially contamination since if harmful substances are released into the nature, there can be unknown impacts in the long term.

Barrick is one of the largest multinationals. They invested 3 billion dollars in the development of the project, and they were never able to open the project to start it, because they didn't comply with the water discharge and water quality regulations. The operation was closed down. (Interviewee 10.)

Table 4 summarizes the water risks identified from the research data. Firstly, Table 4 examines characteristics of an identified water risk in a water scarce region. Secondly, the stage of a mining project in which the risk can occur is described. Then the probability and consequences of the risk, which were analyzed by using the risk matrix in the interviews are explained. The sixth column includes an analysis of the risk management issue causing the risk. Finally, the two last columns describe the case SERENE solution and its impacts on the identified risk management issues.

4.3 Mitigation of identified risks through case SERENE

SERENE is trying to respond to the prevailing challenges by bringing a new water quantity and quality management system (WQQM) to the market of the mining industry. The solution is an IIoT based technical application platform. The software is integrated in online sensor measurements which enables a real-time monitoring of the mining site's

water balance. The customer segment for the WQQM solution is minerals and processing industry. (SERENE proposal, 2017.)

4.3.1 Purpose of the case SERENE

Water scarcity is increasing and creating challenges to the water supply. Water negative sites have lack of available water resources for their operations which can cause production losses and product quality problems to a mining company and societal and environmental issues locally. Today, mining companies have higher sustainability targets. In addition, the environmental legislation is stricter which creates the need for new solutions that enable the compliance with the quality, environment, health and safety requirements. Therefore, the mining companies are trying to find solutions to these strategic water management risks as water is becoming a strategic issue. The purpose of the SERENE project is to bring a new solution to the market which would address these prevailing issues. (SERENE proposal, 2017.) The summary of the SERENE project's proposal is the following:

Project aims at bringing a new solution to market to improve dynamic, predictive water balance management capability; reduce water related risks; and enable increased water recycling with decreased impacts on production performance. Project validates the solution under dynamic production conditions and quantifies the value-add and risk reduction aspects and helps the mining industry drive sustainable water use and environmental performance. (SERENE proposal, 2017, 1.)

The first sentence of the summary enlightens the solution's capabilities to be dynamic, predictive, reduce risks, increase recycling and enhance the production performance. One of the main aims is to reduce water related risks even though the other mentioned capabilities support the risk reduction of the water use. The SERENE proposal paper separates the risks in water scarce and water positive regions. The risks of water scarce regions are described to be challenging because many mine sites are located in a region where water resources are far away. The competition for freshwater resources is high, and the companies are facing conflicts with the local communities. In addition, the paper brings out the issue of tightening environmental permits. There can emerge socio-

political, geo-political and reputational risks which have led mining companies to adopt strategies that support the recycling of water. (SERENE proposal, 2017.)

The SERENE proposal paper discusses the topicality of risks management in the mining industry. The proposal paper highlights the need for new solutions in the industry as there have been major risks that have realized in recent years. The paper brings out the realized Samarco dam collapse in Brazil in 2015 which resulted in a massive environmental disaster and death of 19 people. (Mining technology, 2018.) After the proposal paper has been created, another dam accident has realized in Brazil, which caused the death of 169 people and 141 people are still missing. The environmental impacts were massive as well, as millions of tons of mining waste was released into the region. (Mining technology, 2019.)

Hence, it can be concluded that the mining industry's water related risks identified in the empirical part of this thesis go align with the risks emphasised in the SERENE proposal paper. The SERENE proposal paper summarizes the needs of the mining industry to:

- a) ensure water availability
- b) ensure safe management of large volumes of excess water and
- c) identify, and predict environmental risks related to water resources and future operations. (SERENE proposal, 2017, 4.)

4.3.2 Identified risks through the case SERENE

The relation of the SERENE project's approach and the identified water risks are analysed in this chapter. The purpose and approach of the SERENE project's WQQM solution is described first and then the risk identified from the research data is described. This way, the analysis is carried out by having Table 4 as a framework and showing the SERENE project's risk management approach to the identified water management risks in the same order as presented in Table 4.

There's need for solutions that enable the evaluation and risk reduction of tailings dam management and water ponds. The WQQM solution enables monitoring of the water

quality and quantity through autonomous and wireless monitoring stations which are equipped with IIoT technologies. Real-time water balance management and reporting is enabled through the IIoT technology. It makes possible that the performance of dynamic production conditions can be predicted. However, the WQQM system doesn't provide information about the tailings dam structure, which is important for preventing a tailings dam breakage. Nevertheless, WQQM enables both monitoring of water resources in the tailings dam and monitoring of seepage through the dam, which mitigates the risk of either having a too high quantity of water in the tailings dam or having deformations in the dam structure. The prevention of an acid mine drainage is related to the structure of a tailings dam as well. Monitoring of the water quality and quantity can enable better management of the environmental risks identified from the data. When a mining company gets the information of its water characteristics in its operations, it is conscious about its operations which increases the visibility. (SERENE proposal, 2017.)

If we think about these dam breakage accidents, sure they are rare, but when they realize as the recent examples show, they are very disastrous. (Interviewee 5.)

On water negative sites, there's a continuous need for more water than what is available. The shortfall of water on the mine site is an issue for which WQQM can provide solutions. By providing data of the concentration of water, it is possible to utilize all the water on the mine site by mixing up waters with different pH values. It means that water can be used from various sources and all the water resources on a mine site can be used efficiently. Therefore, the WQQM solution enables recycling and using water many times in the production process because of this feature. (SERENE proposal, 2017.)

Almost all the interviewees described that to mitigate these issues existing within water management of the mining industry, there needs to be solutions that enable better circulation of water in the plant. It means enabling a water balance system that works by circulating as much water as possible internally on the mining site, so that it would not be necessary to take a large quantity of raw water for the production process. Then the fresh water consumption and effluent generation can be minimized, and available water

can be safely allocated for other needs. The quote below is an example of the views on the circulation of water.

If we think about this technology, water recycling. It's pretty much. If water can be used less, it's another thing but I feel that it is almost harder way. So, to finish one, because the process needs a certain amount of water in itself, but water recycling, if it would be possible to use same water for a couple of times. (Interviewee 4.)

Water management of a mine site is directly related to the external water hydrology and weather events. The WQQM forecasting feature is intended to help with the preparation of the water use on a mine site. It creates visibility to water storages and provides information on the volume of stored water. When the mining company has the data of upcoming weather conditions, and they are combined with the data of existing water resources, a mine can prepare for example for heavy rain, by discharging water beforehand which can mitigate the risk of a flood. Therefore, the solution can guide the planning of water management and prepare to control its storage capacities for upcoming events. (SERENE proposal, 2017.)

So, water scarce regions, the frequency of a flooding is often times very rare. Or actually at the same time, water scarce regions mines will allow water to accumulate in the tailing dam, because they want to use that water later in the future. But then if they suddenly have a wet period come through, they might not actually be able to get rid of that water fast enough. (Interviewee 9.)

The contamination of water is a common water management challenge in the mining industry. The SERENE project's WQQM solution tries to respond to the water quality issues in the industry. The water quality is affected by different chemicals used in the production process which cause the contamination of water resources. The shortage of water on a water negative site can often lead to a poor quality of usable water resources which causes production losses and has a negative impact on the product quality. Besides process water, the WQQM solution can monitor natural and discharge waters, which is

important for managing environmental water risks and therefore social impacts as well. The WQQM solution enables monitoring of the water quality in different environmental conditions and production stages. Water quality monitoring is possible due to monitoring stations which are equipped with IIoT technologies that enable real-time monitoring of the water quality in the mining site. (SERENE proposal, 2017.)

The risk of the water contamination is related to the environmental permits, which were identified to be an important factor for the mining companies from the business perspective. The WQQM solution enables that the company is aware of the concentration of water. The online monitoring provides data of the quality, which would mitigate the risk of contaminating the nature by accident. The development of environmental permits was brought out by the interviewees, which are seen to get stricter in the future. Environmental permits concern especially issues related to the contamination of water. The data indicates that the environmental permits are directing mining companies to seek for new solutions in which they could invest so that they would not exceed the permission limits and stay competitive in the market. Below there is an example of how experts described the tightening environmental permits.

Well they are stricter every time. They are being very tough on water issues in terms of quality, discharges, water use, also monitoring. So, they are becoming much stricter for mining companies. Because for farming companies they don't have to comply with anything. They don't have specific requirements so if they discharge nitrite to the water it's fine, but nobody is actually doing monitoring for them. It's mining companies who are under the pressure. (Interviewee 10.)

To summarize, the data analysis shows that the risks of the mining industry are hard to assess. The SERENE project's WQQM solution provides solutions to many risk factors prevailing in the industry. Risk management should be simpler and more efficient. The mining industry seems to lack visibility of operations. The WQQM system will provide a solution to this issue but it is hard to assess the solution's capability to mitigate environmental and societal risks in the long term. The mining industry is very dynamic, and the adoption of new technologies has enabled the development of the industry so far

as well. However, there can be hidden risks in the product implementation as the prevailing risks in the industry seem to be difficult to assess.

Table 4. Identified water risks in water scarce regions

Identified water risk	Characteristics of a water scarce region	Stage of the mining project	Probability	Consequences	Risk management issue	Case SERENE solution	Case SERENE impact
Tailings dam breakage	Environmental damage due to high concentrations because of high evaporation	Operation stage or post-closure stage	Rare, but has happened all around the world	Can be hazardous or catastrophic. Fatalities, destroying the nature.	Mismanagement of tailings dam due to the insufficient risk assessment or regulation	Provides real-time information about the quantity and quality of water in the tailings dam	Doesn't prevent a tailings dam breakage. Mitigates the risk of having too high volume of water in the dam
Shortfall of water to the mine site	No water for the production process. Local water resources might be allocated for other uses	Relevant in all stages of the mining project	Likely, happens every year in some water scarce regions	Mostly economic consequences due to stop of production or project closure	Can be an environmental reason or misrepresented calculations of water resources	Provides information of alternative, available water sources, forecasting provides more time to prepare for the incoming changes, enables better planning of water management operations	Enables more efficient use of water resources through optimization on a site and therefore mitigates the risk of water shortage
Flood on the mine site	Can be caused by a heavy rain season but rare on water scarce regions	Operation and post-closure stage	Rare, as there's not much rain on water scarce regions	Can cause environmental damage when local waters and nature are concentrated	Lack of information on weather circumstances, bad preparation	Forecasts on the hydrological circumstances and provides information about the water quantity.	Short-term forecasts prevent the risk of having unexpected quantity of water in the water ponds, forecasting provides more time to prepare for the incoming changes
Contamination of process water and dischargeable water	The impact of impurities can be much higher due the concentration effect	Operation and post-closure stage	Possible or likely	Can pollute local waters if discharged contaminated water. Polluted drinking water for locals. In the production process can lead into bad quality of a product.	Lack of information of the water quality, company's lack of motivation for purifying water	Provides information about the contamination, optimizes quantity of water and quality of dischargeable water	Enhances the possibility of better dischargeable water quality than the permits demand or compliance with the tighter permit limits in the future

4.4 Synthesis of the findings

Figure 7 describes how the SERENE's WQQM solution addresses the water issues identified from the research data. Table 4 already summarized the environmental water risks identified from the data, but Figure 7 describes the risk development drivers of the water use of the mining industry in water scarce regions. The water risk issues identified are on the left side of Table 4 and the arrows point to the right side where the SERENE project's solutions are described. These six issues presented in Figure 7 were emphasized in the research data. As the environmental risks identified in Table 4 are specific water risks that occur in the industry, the issues in Figure 7 are more general drivers in the industry that impact on water risk management. The issues can be strategic drivers that direct water risk management of the mining industry.

Issue described by the experts	Case SERENE approach
1. Environmental permits are getting stricter in both in EU and in Australia and Chile.	Real-time data on water quality can enable better planning of water management investments and improve water resource use in mining operations. Mining companies can prepare for the trend of straightening regulation.
2. Societal discussion and NGO activity about the water allocation has increased in water scarce regions.	Enhances the achievement of a social licence to operate due to the water allocation for other local uses. Potential risks are assessed real-time which can enhance the local acceptance of operations.
3. Inner circulation and reuse of water are desired solutions for water scarce regions.	Possibility to reuse water and water circulation which leads into a more efficient water balance. Water quality can be optimized for the production Water can be allocated for other local uses.
4. Mining companies are not aware of their water balance in terms of the process water quality.	Data provided by the system creates visibility of the operations. A mining company can learn how to optimize its processes.
5. Economic performance is driving mining companies' interests.	WQQM enables cost optimization. Water use and treatment operations can be optimized. Resources can be freed to focus on core operations, not on manual updating of water related performance indicators. water use can be optimised and resources can be used effectively, which can lead into savings.
6. Water is going to be an even more scarce resource in the future.	Efficiency through the circulation and reuse of water through the optimisation and utilization of the available water resources efficiently.

Figure 7. Environmental risks and the SERENE project's WQQM solutions

5 DISCUSSION AND CONCLUSIONS

5.1 Theoretical contribution

The purpose of this study was to examine water risks management of the mining industry in water scarce regions. The research questions are focused on understanding water risks in the mining industry and the assessment of the SERENE project's water quantity and quality management system in relation to the risks identified. The theory part of the study examined water risk management and water scarcity context in the industry. The empirical part of the study was carried out through semi-structured interviews which were conducted to have expert views on the subject and find out what their prevailing perceptions on water related risks in the mining industry are. By means of the empirical data, the different characteristics of risks in water scarce regions were identified and divided into different sections. The identification supported the assessment of the SERENE project's WQQM solutions approach to the issues within water risk management. The SERENE project's risk management approach was analyzed through the identified risks. Four propositions are presented in this subchapter, which were identified from the findings of the study. The propositions are presented in this chapter by combining the theoretical contribution and empirical part of this study.

Proposition 1. Mining industry's water risks are multidimensional.

The first proposition addresses the theoretical conclusions of this study, in which the mining industry's water related risks were defined to be complex and site specific. The complexity is related to the different risk categories and stakeholder interests on risk management which was identified from both the theoretical and empirical part of this thesis. Water risk management of the mining industry has developed into a direction in which water risk management is the strategical consideration of different levels of risks (Boatright, 2011). In addition, the sustainability has become an important part of the mining companies' strategy, which requires the consideration of the environmental and social impacts of the operations. (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018.)

These developments are creating challenges to the mining industry as it is a complex industry in what comes to water risk management (Domingues et al., 2017).

Firstly, there are several different mine sites in the mining industry, which makes it hard to make general assumptions about the risks (Nothey et al., 2016). Therefore, consideration of the local environmental and hydrological context is needed for managing water related risks (Northey et al., 2017). Secondly, the multidimensionality of water risks is due to the societal, climate change and technological challenges in the mining industry which should be included in risk management (Domingues et al., 2017). Therefore it is suggested to approach risks from a holistic perspective so that different stakeholder impacts of possible risks would be considered (Franks et al., 2012). In addition, Domingues et al., (2017) suggest that there's a need for new approaches on the mining industry's risk management which address the complex character of the industry.

The multidimensionality was identified from the empirical part as well. Different risk categories were identified from the research data. The identified risk categories were technical, economic, environmental, social, company brand, reputation, safety and risks related to environmental permits. Besides the different risk categories, different stakeholder perspectives impact on the risk management approach. Interests of the stakeholders might differ from each other, which explains why their conceptions of risks are not consistent. There can be a significant social pressure on water scarce regions as the limited water resources should be allocated among different stakeholders. In addition, the cumulative impacts of water risks were highlighted in the empirical data. The cumulative impacts of risks increase the multidimensionality as the timeline of the impacts of risks can be very hard to estimate. Therefore, the relation between short term impacts and long-term impacts of risks create uncertainty to risk management. Especially the environmental risks were seen to be complex as it can be very difficult to assess the impacts on the environment in the long run if the local waters are disrupted.

The empirical data emphasized the multidimensionality in terms of taking these different aspects into account when assessing and managing water related risks. Therefore, the interviewees considered that risks should be assessed on a case by case basis in the mining industry due to the variability of the industry. However, there can be general solutions

that work in certain cases which can be beneficial solutions for most of the mining companies. Especially if considering risk management in the industry as a whole, there can be certain identifiable features that direct the development of risk management as a whole in the industry, which has impacts on the company and site specific risk management objectives. Therefore, water risk management can be multidimensional depending on time, locational circumstances, stakeholders and company's internal performance.

Proposition 2. The most relevant environmental water risks in water scarce regions are the shortfall of water and contamination of water.

The second proposition comprises the most probable water scarcity related risks in the mining industry, based on the research of this study. Low latitude regions are facing water scarcity because there's high temperature which causes the evaporation of water resources. It is typical, that there's lack of soil water in arid regions which can impact on the societal wellbeing. (Falkenmark et al., 2007.) Most of the mining industry is in these kinds of regions, where the water availability is low (Northey et al., 2017). There's continuous need for freshwater imports in water scarce regions, and therefore the water supply can come from far away, which can be challenging (Northey et al., 2017). The water related challenges can be related to the infrastructure, water balance and quality (Wolkersdorfer et al., 2004). The shortfall of water is from the mining operations' perspective a situation in which there's no water for the production process. The available water resources can be allocated for other uses such as the agriculture or domestic use. (Northey et al., 2017.) It also leads into a situation in which there's a higher competition and pressure among different stakeholders. Therefore, the limited water resources can be allocated by prioritizing the local people.

There are also global predictions of accelerating water scarcity and climate change (IPCC, 2018). Global scale predictions seem to be too wide issues if examining the mining industry's water risks. However, studies focusing on the global predictions' impacts on the mining industry indicate that warmer temperature and changes in the precipitation can cause problems related to the water balance, water quality and infrastructure. They can influence on water risk management of mining operations. (Northey's et al., 2017.)

Therefore, there's a growing concern about how to manage these waters-related risks as the availability of water will decrease. The contamination of water can refer either to process water or discharged water. The quality of process water affects the product quality and quantity as contaminated water impact on the production processes. The risk category related to this situation can be economic and internal, as the profits of the product can suffer. In addition, it is not aligned with the sustainable development, as the production is not effective in that case. When referring to the contamination of dischargeable water, the consequences are rather external, and the risk can cause wider societal damage. Water discharges are restricted by environmental permits which define what quality and quantity of water can be discharged and where. (Frederiksen, 2018.)

3. Proactive consideration of the mining industry's water risks is a strategic preparation for long term viability.

The conclusion of this study is that the performance of water risk management is good if the negative impacts of the mining industry's operations are minimized. The negative impacts refer to unwanted situations that cause damage to the environment or society or the company itself. (Domingues et al., 2017.) Water risk management reflects the objectives of the sustainable development. Therefore, in the long term, successful water risk management can be compatible with the sustainability objectives and strategy of a mining company.

The sustainability is emphasized in the strategy of many mining companies today (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018). To remain viable in the market, a mining company needs to prepare for drivers of change. Studies on water scarcity predict that the availability of freshwater resources will decrease in the future and the issue of water scarcity will accelerate. (IPCC, 2018.) The strategic, long-term consideration of water related risks is a preparation for these foreseeable future projections. However, the development of the water use in water scarce regions seems to be increasingly difficult for the mining industry and other industries.

In the mining industry, environmental permits are an important part of water management as they create restrictions to the dischargeable water quality and quantity. (Frederiksen, 2018.) Flörke et al. (2013) suggest that it can work as an incentive for investing on new water saving technologies and investments. The environmental permits and regulations were described to be a driver of the mining industry's risk management approach in the empirical data. The direction of regulations and environmental permits was seen to be tightening due to the stakeholders' awareness on environmental impacts and their demands. This thesis indicates that regulations have a prominent role in the shift of the framework in which the mining companies need to comply with water risk management.

It seems that mining companies struggle with complying with the new legislation or regulations and see them as a threat against their business. Instead of focusing on long term benefits of preparing for these future challenges, they focus on short-term profits. To acquire a competitive advantage, mining companies should consider the upcoming changes as a possibility and adapt their strategy to comply with the new requirements. If the changes are seen as a threat – and therefore including many risks, they need to take actions continuously against emerging and accumulating risks. The direction of the industry seems to be quite clear, as the long-term changes were brought out by all the interviewed experts. Therefore, the proactive consideration of the long-term water risks of the mining industry is preparation for business activity threats.

4. Desired solutions for the prevailing environmental water management risks in the mining industry are solutions that enable water recycling such as the SERENE project's WQQM solution

The mining industry operates in dynamic and complex environments, which means that water related risks depend on the unique circumstances on a certain mine site (Wolkersdorfer & Howell, 2004; Northey et al., 2017). Therefore, water management of the industry can be challenging (Kohl et al., 2013; Northey et al., 2016; Frederiksen, 2018). This study demonstrates that the mine sites located in water negative regions are especially in need for new solutions to maintain their operations. This study shows that the experts working with the mining industry's water issues, consider that water related solutions that enable the inner circulation of water in a mining site and enable a more efficient water use in water scarce regions are desired in the industry. Therefore, the

WQQM solution commercialized within the SERENE project is a desired solution in the industry that utilizes the latest technology.

Uncertainty reflects the nature of risks. The uncertainty describes risks as the situations causing risks are situation specific and even though a risk might seem to be uncertain, there's still possibility that the event occurs in the future. (Flaus, 2013.) There can be external or internal impacts causing uncertainty for an organisation (ISO 31000, 2018). The external uncertainty can include changing mineral commodity prices, changes in global demand, new regulations, especially environmental regulations, which are requiring more actions from the industry (Kumar et al., 2015). The internal uncertainty in the industry reflects the trend related to lower ore grades, increased production and there is relation to economic resources and increased amount of waste rock which makes the restoration more difficult. They can lead into a higher consumption of water, energy and cyanide. (Mudd, 2010.)

Uncertainty describes risks as their consequences and possibility to occur are situation specific. It means that the potential of a hazard event is uncertain and might occur in the future, causing damage. There are external and internal impacts that can cause uncertainty to an organization. To meet the objectives and support a strategic guideline setting and decision making, an organization shall manage its risks. (Flaus, 2013.)

5.2 Contribution to the organizational practice

The aim of this study was to create understanding of water related risks of the mining industry by having water scarce regions as a core focus. Through studying the risks, the purpose was to assess how the commercialized WQQM solution would be capable to reduce water related risks in the industry. The purpose was not to identify industry wide risk conceptions but to identify characteristics of water risks of the industry in the context of water scarce regions. The findings of this study indicate that the risks of the mining industry are seen to be complex and site specific. The complexity was seen to describe risks due to different risk categories and dissenting interests of different stakeholders which impact on risk management of the industry. Moreover, cumulative impacts were

emphasized to complicate management of risks as the long-term impacts of risks can be difficult to assess.

However, it was possible to identify certain risks which were presented in the findings. The identified risks were seen to be caused by mismanagement of water on the mine site which can be caused by the underestimation of existing risks. To address the underestimation of risks, the environmental permits and regulations are suggested to direct the shift towards more responsible risk management as it forces companies to comply with the restrictions in order to continue their business. The empirical data shows that the mining industry has developed significantly in the recent decades. The future shift of the industry is seen to be impacted by the global trends, such as global warming and population growth, which are seen to enhance the pressure of fresh water resources. Therefore, the authorities are expected to respond to the societies' expectations of prioritizing their access to clean water. From the mining industry's perspective in already water scarce regions, it means that the industry needs to find new solutions and practices to these issues.

The risk identification of this study shows that mining companies are confronting a need for new sustainable water solutions which would address the problems with the water availability and mitigate the risks of a dam breakage, contamination of water and flood. The case SERENE examined in this study, seems to provide a beneficial solution to the water scarce regions as it provides solutions to these risks by its capability to monitor the water quality and quantity on the mining site, provide real-time data and reporting of water balance management and its capability to work in dynamic production conditions. The empirical analysis shows that the highlighted solution to address the risk of a water shortage in water scarce regions was recycling of water. The WQQM system enables the reuse of water which enables the recycling of water resources. Therefore, it can be assessed to reduce the identified risks. However, the future will show how these kinds of new water management systems will mitigate risks in the real-life conditions. Nevertheless, the findings of this study show that there's a clear need for this kind of solutions in the mining industry.

5.3 Evaluating the study and suggestions for the further research

Limitations of a research can be discovered through analysing its reliability and validity. The reliability refers to the repeatability of a study which means the ability of a research to provide non-arbitrary results. The validity means the ability to measure exactly what is meant to measure in a research. (Eriksson & Kovalainen, 2008; Hirsjärvi & Hurme, 2011, 231.) The reliability of this study may be evaluated through examining the research methodology and how the methodological process is conducted and explained in this study whereas the validity may be evaluated on the grounds of the capability of this study to answer the research questions. However, there are several ways to evaluate the validity of a qualitative research method (Eriksson & Kovalainen, 2008). As concluded in this study, water related risks are multidimensional and therefore this is a phenomenon that can be studied in many ways. The methodology used for this study and the different stages of the research process are explained in this study to enhance transparency. The objective is that the transparent description of the course of the study directs to the reliability and validity.

The methodological decisions when conducting this study were made on the basis that the study would create understanding of how the experts on the field of the mining industry analyse the risks related to water scarcity. Semi-structured interviews were conducted with ten experts who presented different perspectives, to gain different aspects to the examined phenomenon. The number of interviewees in a qualitative research can be decided through the data saturation. It means that after the interviews have been collected, new interviews can be conducted until new ideas run low. (Francis et al., 2010.) The data collection was conducted by having the data saturation as a basis for this study. When the data from the expert interviews were gathered, the data analysis was conducted through a content analysis process. The content analysis was chosen as a research methodology as it suits well for analysing multifaceted phenomena. (Elo & Kyngäs 2008.)

This study consists of a real-life case the SERENE project and the study is conducted for Outotec as part of the project. Real-life cases are often used in a business research because then it is possible to research complex business issues in an accessible format. (Eriksson

& Kovalainen, 2008.) The SERENE project's material and nature of the case was analysed in this study. The SERENE project's aim is to bring a new water balance system to the market of minerals and metals industry. However, the technicality of the issue can be suggested as a limitation of this research. The issue of a case study research can be its practicality and lack of scientific rigour. (Eriksson & Kovalainen, 2008.) Therefore, the findings of this research can be applicable to the SERENE project itself, but the water scarcity issues of the mining industry might need a more in-depth analysis to generalise the findings. In addition, it can be hard to make any general assumptions due to the complexity and variability of the mining industry's water use.

The findings of this study show that mining companies operating in water scarce regions, have many challenges related to water risk management as the risks in water scarce regions are multifaceted. Therefore, it is possible that the author's subjective perceptions impact on the content analysis process when identifying water risks from the research data and when analysing the solutions provided by the SERENE project. Subjective knowledge is always included in the results of a qualitative research. The decisions and conclusions leading to findings are dependent on the researcher as the researcher does the methodological decisions. (Tuomi & Sarajärvi, 2018.) This research has followed an abductive research process, which refers to an iterative research process in which the process doesn't follow a linear design (Eriksson & Kovalainen, 2008). The abductive grasp of this study was realized so that when the theoretical research process was still unfinished, the empirical part of the study was taken under the examination. By doing so, the researcher could focus on the theory to be aligned with the theoretical framework and otherwise.

There are some suggestions for the future research on the thesis subject. Water risks of the mining industry in water scarce regions can have many perspectives to approach the subject. As the water risks depend on the location of the operations, the research could focus on a certain country and the circumstances in relation to water risk management. Kunz and Moran (2016) suggest that there's a need for further research on how the water shortage can impact on financial costs in the mining industry. In addition, the social licence to operate has become an important factor for the long-term success of the mining companies. (Vanclay, 2012.) Sustainable development has also become as part of the

strategic long-term consideration of the mining companies (Kapelus, 2002; Jenkins, 2004; Frederiksen, 2018). There are many options to research these guidelines of the development of the mining industry. For instance, an in-depth understanding would be created by conducting an empirical case study research, focusing on the mining companies' approaches on water risk management and evaluation of their water management activities. Besides the impact on the performance on different risk category levels, the research would possibly provide an important insight for the mining industry itself as well as for different stakeholders.

However, it remains to be seen whether the mining companies will adopt new sustainable water solutions such as the SERENE project's WQQM solution and what the impacts will be in the industry. An interesting approach for the further research would be an additional longitudinal case study, focusing on the utilization of sustainable water solutions such as the SERENE's WQQM solution as a water risk management method, which would provide an insight on how the solution can mitigate risks in practice. The research would be based on statistical information provided by the solution and possibly on interviews regarding different stakeholders' perceptions.

The challenges related to water scarcity seem to remain in the industry if actions will not be taken. The identified water scarcity risks in this study seem to be an accelerating concern in the future which may require the mining companies to search for new approaches. A further research and practical contribution are desired to overcome these challenges. Eventually, addressing the water related risks of the mining industry in water scarce regions is an inseparable part of sustainable water management, enabling the wellbeing of societies.

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APPENDICES

APPENDIX 1 Half structured interview

1. Background of the interviewee

What kind of job description do you have?

How long time have you been working in the industry?

How would you describe your expertise in water issues?

2. Definition of risks

How do you define something as a risk?

What is the benefit of risk assessment?

3. Water use in water scarce regions

How would you describe water scarce areas?

What impacts does water scarcity have on societal level?

What problems do companies operating in water scarce areas have?

4. Risks related to water scarce regions in the mining industry

How does water quality and availability affect the production process?

Could you tell about risks in water scarce regions?

What environmental risks occur in water scarce regions?

What social risks occur in water scarce regions?

What economic risks occur in water scarce regions?

What political or regulatory risks occur in water scarce areas?

What technological risks occur in water scarce areas?

What operational risks occur in water scarce areas?

On scale from 1 to 5, how would you assess firstly the risk you mentioned regarding the consequences caused by the risk and secondly how often the risk can be realized

5. Management of water related risks

What methods exist in the mining industry for managing risks in water scarce regions?

How has water management changed in recent years?

What are the problems related to water management in water scarce areas?

How has the sustainable development been considered in the mining operations' water management systems?

6. Future prospects in water use in the mining industry

How do you see the development of water scarcity in the future? Which factors have an impact on it?

What kind of future prospects does the mining industry's water use have in water scarce regions?

How does the development of technology affect the mining industry's water management in the future?

APPENDIX 2 Risk matrix used in the interview

RISK LEVEL			Consequences				
			1. Negligible	2. Minor	3. Major	4. Hazardous	5. Catastrophic
Frequency	Event occurs many times per year	5. Almost certain					
	Event occurs annually	4. Likely					
	Event occurs more than once in 5-10 years	3. Possible					
	Event occurs once in every 20-50 years	2. Unlikely					
	Event occurs once in every 100 years	1. Rare					

